CARBURETTORS
VAPORISER
AND DISTRIBUTING VALVES
USED IN INTERNAL COMBUSTION ENGINES:

BY

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SECOND EDITION, REVISED AND ENLARGED.

With over 190 Sectional Illustrations.

LONDON:
CHARLES GRIFFIN & COMPANY, LIMITED,
EXETER STREET, STRAND, W.C. 2.
1919.

PREFACE.

THE object of this treatise is to present in a clear and concise form information specially useful to practical engineers, designers, and others engaged in the construction of internal combustion engines employed for automobile, stationary, and marine purposes

It has been the endeavour of the author to treat exhaustively such important subjects as carburettors, vaporisers, atomisers, and gas mixers, also the various forms of distributing valve mechanism, used in petrol and petrol-paraffin high-speed motors, gas engines, and heavy-oil engines, in a much more thorough manner than has been hitherto attempted. In so doing, the text and illustrations contained in the original edition of this work have been largely drawn upon.

The attainment of the high-speed petrol motor to its present high degree of perfection is admittedly due to the close attention which such details as carburettors, ignition apparatus, and valve action have received, rather than to any legislative action tending to restrict the provisions of the original Locomotive Act.

The continued development of internal combustion engines for large powers will also in all probability be influenced to a greater extent by the degree of perfection of the methods used for vaporising the various grades of fuels obtainable, and to the extent to which the design and construction of distributing mechanisms for the admission and exhaust of the actuating fluids are brought within the lines of practical application, than to any other factor. For the widest remaining fields of usefulness yet awaiting the further perfection of internal combustion engines, we must undoubtedly look to maritime propulsion, an

application for which an oil engine possesses peculiar advantages, owing to its unapproachable economy in space and fuel: as for a like reason aerial locomotion depends for its very existence on the perfection and intensive development of the petrol motor.

EDWARD BUTLER.

PREFACE TO SECOND EDITION.

THE author tenders his grateful thanks for the very kind reception accorded to the first edition of this book. This second edition would have been issued long ago but for manifold delays owing to the War. The developments of the subject since the work was first written have been so great that it has been found necessary to re-write the entire work, and the publishers have met this need by resetting throughout and preparing numerous fresh cuts, so that the present issue is practically a new book.

Special attention is called to the tendency towards extreme diversity rather than unity in modern carburettor design, to the great number of different forms of paraffin vaporisers and atomising methods for the heavier residual oils; also to the numerous forms of valves and distributing methods for admission and exhaust. The advantages and more favourable applications of the variously specialised designs are commented upon and their limitations and defects pointed out, the purpose now being to deal more comprehensively with and bring into line with present practice such important essentials as carburettors, vaporisers, gas mixers, atomising systems, and distributing mechanism used in high-speed motors, paraffin, gas, and residual oil engines.

E. B.

January 1919.

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CARBURETTORS, VAPORISERS, AND DISTRIBUTING VALVES

USED IN INTERNAL COMBUSTION ENGINES.

CHAPTER I.

INTRODUCTORY REMARKS.

PETROLEUM, in its crude condition, is a dark, pungent liquid, of wide distribution, and, owing to its comparative cheapness and ease of transport, is peculiarly adapted for the economical generation of power. The oil, in its natural state, lends itself to use for power purposes in three distinct ways:—

(1) In specially constructed grates fitted with steam or compressed-air atomisers for steam raising; (2) in slow-combustion or caloric engines; (3) in explosion engines provided with suitable vaporisers or atomisers.

The principal requirements are heating and efficient straining to ensure the removal of all suspended matter, which otherwise would be liable to choke the pipes and clog the feed mechanism. Owing, however, to the intense heat necessary for perfect combustion, the natural unrefined oil does not lend itself for use in small high-speed engines, such as those used for automobiles and motor cycles, for aero craft, launches, yachts, and for the vast number of stationary industrial engines of small power.

In order to obtain a suitable and safe oil for burning in illuminating lamps for domestic purposes, the natural crude oil is subjected to a course of distillation, the first distillates coming over from the still being the benzene series, comprising all the

more volatile constituents, known variously, according to their degree of refinement, as gasoline, benzine,[1] benzoline, mineral naphtha, mineral spirit, motor spirit, and petrol. All these have low flashing points, and require no heat preparation to render a mixture of the vapour and air explosive. In consequence, special regulations are in force in most countries for their storage, distribution, and transport. The weight of the mineral spirit[2] series averages slightly less than three-fourths that of water, the range being from ·650 to ·750 specific gravity, but by fractional distillation motor spirits can be produced having a sp. gr. of ·760 or even ·780. A point to be taken into account is that, owing to their high coefficients of expansion, reservoirs and tanks should never be filled to more than nine-tenths their full capacity, to allow for increase of volume of the liquid, due to temperature variations in ordinary climates.

The ready volatilisation of petroleum spirit at low temperatures makes it specially suitable for use in small high-speed explosion engines, such as are so very extensively used for road-motor traffic, and other purposes mentioned above. None of the series requires any preliminary heating for use in the smallest engine, and can be readily volatilised by the simplest and crudest form of carburettor or atomiser, the essential requirement being an apparatus capable of supplying a *perfectly adjusted mixture* of spirit vapour, or atomised spray and air, to the motor cylinder *under all conditions of load and speed.*

The application of the volatile products obtained from hydrocarbons in their crude form, such as petroleum spirit, benzol alcohol, etc., for the production of motive power in explosion engines, is justified by the peculiar amenability and powerful properties of these combustibles, such advantages off-setting all the precautions necessarily required in handling a fuel so volatile as to be capable of forming an explosive mixture with air without heat or preparation of any kind. Fuels possessing such explosive properties are thus particularly valuable for operating high-speed road-car, cycle, and aero motors, where high

[1] The "benzene" series of aromatic hydrocarbons are always spelt in chemical works with an "e." The "benzine" here alluded to is an impure trade product, always spelt with an "i."

[2] Although classified as a spirit, the higher grades of petroleum, however volatile, are chemically "oils," and will not combine with water.

power duty and capacity for perfect combustion is a *sine qua non*.

Besides this property of extreme inflammability, all mineral spirits constituting the several brands of petrol,[1] as well as alcohol, are, as has been stated, much more expansive than heavy oil or water, the volume increasing 0·0009 for every degree Fahr. increase in temperature; thus 10 gallons of petrol will expand to 82 pints with an increase of temperature from, say, 50° Fahr. to 75°, and it is needless to add that a tank, if quite filled, will be liable to burst with a much smaller increase of temperature than this, unless a ventilating outlet be provided. In this connection it must be remembered that petrol, on escaping, will evaporate and mix with the surrounding air at any temperature, be it ever so cold; and the vapour being heavier than air, will accumulate, unless disturbed, at the floor level, with the consequence that, although not discernible to a person standing in the room, it may yet be ignited by a lighted match thrown down.

The value of mineral and vegetable spirit has long been recognised for use in comparatively small explosion engines, more especially in Europe and America; in the one case owing to the greater scarcity of coal, and in the other to the quantity of spirit (gasoline) available from the numerous refineries. Indeed, mineral spirit lends itself so readily for either supplying carburetted air or spray direct to the motor cylinder that, in spite of the necessary precautions for storage, to prejudice, and to the expense incurred in its conveyance to the user, engines worked by benzoline, benzine, gasoline, and other brands of petroleum spirit had already become very widely adopted before the introduction of the automobile. The method of forming an explosive mixture at this time consisted invariably of a special construction of carburetting chamber through which the motor drew its air supply. In the Lenoir[2] carburettor (1883–1885) the spirit (*essence de pétrole*) was fed into a revolving cage

[1] The designation "petrol" was first used and registered by the writer in 1887, which term has been adopted in this country to include all brands of petroleum spirit.

[2] This is notable as the first application of motor spirit to drive a launch, several having been fitted up by Rouart Frères, at about this time, for use on the Seine.

containing a sponge, which functioned like a spun mop. The vapour whirled out mixed with air drawn through the carburettor chamber, and was thus supplied together with a supplementary diluent to the engine. In another apparatus, air, in being circulated across "trays" kept wet by the injection of a spray of spirit by a pump, became supersaturated; to this was then added a further supply of air before admission to the motor, any excess of spirit draining into a tank below. The benzine or gasoline motor in other respects was not dissimilar to the ordinary gas engine. Various other methods have been used in turn, including almost every conceivable means for bringing air into surface contact with either the spirit itself or with saturated wicks, gauze, or other material, and will be described later under the heading of "Surface Carburettors." The distinguishing feature of carburetting apparatus of this type was their immense bulk; one in particular, known as the Simplex, and supplied by a well-known firm at Rouen, being fitted up as a sort of washing machine for the purpose of deodorising the spirit before passing it on to the carburetting chamber used in connection with an ordinary gas engine.

The next stage in the practice of running stationary engines with spirit was the injection at each stroke of a charge in its liquid form by a small pump. This charge was delivered direct into a chamber surrounding the admission valve of the cylinder, and probably the first successful injector of this kind was used in the Spiel engine, with which the author was associated in 1886. This engine, described later under "Pump Carburettors," was complicated by a slide ignition valve and methylated spirit burner. However, when properly made it showed a distinct advance in efficiency over all carburetted air engines, including even the Etève, with compressed-air atomiser. The principal difficulty experienced in getting this engine to keep up to its work, however, was the correct adjustment of the cam-actuated spirit pump, in spite of this being fed by an over-cylinder tank in which the level could be corrected by an air tube extending to the bottom, the top of the tank (for this purpose) being sealed. In this manner the rate of flow to the pump could be made practically the same for different levels of the spirit. As an additional precaution the pump was provided with

mechanically actuated inlet and outlet valves held up to their seats by strong springs; *apropos* to which, it is noteworthy that an almost identical plan to this has since been adopted in an early form of injection pump for the Diesel high-compression engine. However, despite elaborate strainers, dirt would occasionally get on the valves, and no adjustment of the pump would remedy its effect on the engine. In the Charteris gasoline engine, of which the writer has similarly had some experience, a pump was also used; but in this case, as in many modern oil engines, the pump supplied the gasoline charges in excess, the "injection" into the carburetting or mixing chamber immediately over the admission valve of the cylinder being controlled by a separate valve. This engine, as in the aforementioned, was governed on the "hit-or-miss" method, excess spirit being returned to the tank by the action of the governor on the cut-out strokes.

Guided by the experience gained in the working of mineral-spirit engines of various types, the author designed the *induction-jet atomiser* carburettor illustrated under this heading, the action of which was corrected by a float-controlled feed cistern in which the spirit was maintained at constant level, this being the first instance of the application of this principle to a jet carburettor. In order to obtain a uniform mixture at varying speeds of the motor piston, this carburettor (which worked on the inspirative principle) was provided with an automatic compensator, by which means excessive suction on the petrol feed was automatically compensated for at high speeds, and the engine permitted a wide range of speed under the control of the mixture throttle. In this connection it is well to bear in mind that a column of petrol (0·75 sp. gr.) 40 in. high is equal to 1 lb. per sq. in.; that a column 2·31 in. high equals 1 oz. per sq. in.; that a depression of 0·25 lb. per sq. in. is equal to a column of petrol 9·25 in. high; that the usual "*depression*" in modern carburettors seldom exceeds 6 in. Carburettors of this kind have been fitted by the author to petrol, gas, paraffin, and semi-refined oil engines of various types, ranging from high-speed motors with small cylinders only 1½ in. in diameter up to engines with a 18-in. cylinder; the first application having been made in connection with a small

automobile constructed in 1887, and provided with two double-acting motor cylinders.

The use of the light oils known as benzine was at this time probably more common on the Continent than in this country or America, two Continental inventors having adapted the benzine motor to the automobile. In which connection Benz turned his attention to the propulsion of a road carriage and Daimler to river boats, the latter motor, being subsequently improved in its application to road carriages in France by the well-known firm of coachbuilders, Panhard & Levassor. Both the motors referred to worked with a surface carburettor constructed in each instance very closely on the lines of the examples illustrated in figs. 1 and 2; a carburettor designed on similar lines was shown in 1885 at the Inventions Exhibition, South Kensington, by the writer. In carburettors of this kind the air is made to bubble up through, or circulate closely over, the surface of the spirit, contained either in a carburetting chamber supplied from time to time from a reservoir, or, as in the illustration, where the air is drawn into a rose diffuser constructed to float on the surface of the spirit, by which means the resistance to the passage of the air through the spirit can be maintained constant, the degree of carburetion being controlled by a supplementary air supply according to the requirements of the motor. The objection to surface carburettors generally is the difficulty of obtaining correct mixtures at varying speeds and temperatures, their action being influenced by the density of the spirit used, to temperature, and by the road surface, and in no case can they be constructed to work with any degree of constancy under the many and varying conditions associated with the running of an automobile, and they would be impracticable in an aero motor, owing to lowering temperature and varying inclinations.

Although the float-feed spray carburettor with automatic air regulation was in use by the writer as far back as 1887, this principle was not adopted to any extent in connection with automobiles until quite twelve years later. Its use is now, however, universal in all petrol motors, whether for boat, aerial, or road-car propulsion, the float carburettor with induced jet and automatically variable action being now used

even for the smallest cycle motor, the form of float, with direct feed and central spray jet, following either the Maybach model introduced in 1893, or with a hinge as used by the writer.

In tracing the development of the carburettor as used in the modern automobile, it would occupy more space than can be spared if all the various forms were to be described and illustrated, considering the hundreds of makes of motors now in use for one purpose and another, and recognising that many makers introduce improvements and changes in design from season to season, an ever-increasing number of which, it is needless to add, are destined successively to become obsolete as time goes on. Representative examples illustrating the various stages in the development of the carburettor, including the more important changes in design of surface, compressed-air jet, force-pump jet, gravitation jet and induction jet atomiser carburettors, are first described, followed by a few descriptions of the best-known induction jet carburettors arranged with automatically adjusted mixture control, such as are now in more general use for high-speed motors of the automobile type.

Important as the petrol motor has become for the purposes named, paraffin engines are none the less useful for a number of other purposes, and as this fuel is comparatively safe and much less costly, there has been much endeavour in the application of the several flash-proof brands of the paraffin (kerosene) series to general industrial purposes, including motor vans, lorries, motor ploughs, field and road tractors, motor boats, etc.; while the heavier residual oils (known as fuel oil) and the intermediate distillates, such as gas or solar oil—*i.e.* crude oil *minus* the lighter constituents,—have been largely pressed into service for engines adapted for higher powers, as now increasingly employed for cargo boats of all sizes, submarines, electric-light and pumping installations. The numerous developments in vaporisers and atomisers used in both the paraffin and fuel-oil types of engines are described and illustrated at great length and in considerable detail. Lastly, there is the consideration of distributing valves, that constitute so essential a feature in all four-stroke engines, and

the deciding factor in all two-stroke engines having a piston controlled exhaust. These also have been most extensively dealt with, and illustrate the many difficulties experienced in the keen and persistent endeavour to improve on the cam-actuated clack, which continues, despite the considerable enterprise evinced in the development and introduction of improved methods, to be the generally accepted and universal practice.

CHAPTER II.

SURFACE, PUMP-INJECTION, AND SNIFT-FEED CARBURETTORS USED FOR BENZOLINE, PETROL, AND ALCOHOL MOTORS.

Surface Carburettors.—*Class I.*—The usual method at first adopted in surface carburettors was to supply, by means of a bye-pass to the main air-induction pipe of the motor, a proportion of vapour and air, generated from a carburetting tank or reservoir. Acting on this principle, various expedients have been used in turn for carburetting the air; such as pumping or forcing air through and over the surface of the liquid, as adopted in the early Benz, Daimler, De Dion, and other automobile motors (see figs. 1 and 2). Carburetion by saturated cotton and wire gauze wicks has also been tried by many pioneers, and various forms of mechanically actuated stirrers and agitators used. One early device employed by Lenoir consisted of a fine wire cage containing an absorbent supplied with mineral spirit, and arranged to revolve at a high speed in a carburetting chamber, the vapour thus driven off acquired a vortex motion, and was either separately mixed, or allowed to mix with air drawn through the carburetting tank. Others of this class were the Delahaye, Lamaudière, Aster, Philips Lufbery, etc.

An attempt was made by Treeton to remove the objectionable feature associated with all surface carburettors (viz. the tendency for the lighter constituents of the fuel to evaporate in advance, thus leaving a residuum). He used a shallow carburetting chamber in which mineral spirit was maintained at just sufficient depth to cover a series of immersed perforated

pipes, through which air was drawn by the action of the motor piston, sufficient heat being imparted to the under-side of the carburettor to compensate for loss caused by evaporation; this was patented (8584) in 1885. In the year previous to this the author applied for a patent (13541) on somewhat similar

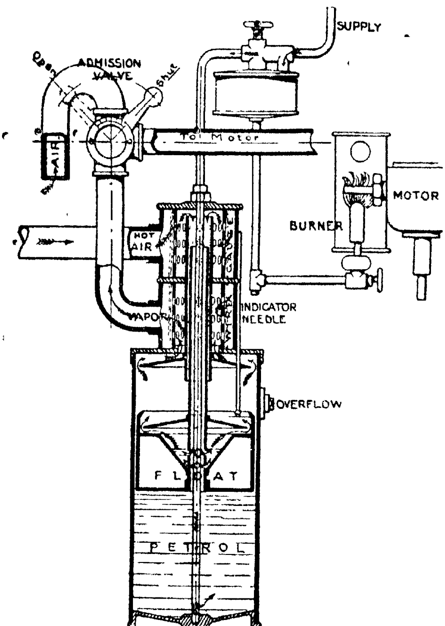


FIG. 1.—Daimler bubble bubble surface carburettor.

lines, in connection with a design for a motor tri-car which he exhibited at the 1884 Stanley Show, and in the following year at the Inventions Exhibition (South Kensington).

Another attempt in the same direction was made by the author three years later to remedy this fault, in a simple form of domestic motor run on benzoline, by using a carburettor consisting of two chambers, one over the other, the dividing partition

plate between them being utilised to carry a series of tubes extending down to within a quarter of an inch or so of the bottom of the lower chamber; in these tubes were inserted a series of wicks, the upper ends of which were held up by clips in the carburetting chamber above. The wicks thus dipped to the bottom of the spirit in the lower chamber and were only exposed at their lower ends, yet, despite the precaution of sealing the space over the liquid from the carburetting chamber above, the quality of the spirit gradually deteriorated during the working of the motor until a stage was reached when the residuum had to be emptied out.

During the period dating from 1876 onwards, until the drawbacks of surface carburetion were more generally realised, several attempts had been made to form a combustible mixture from volatile inflammable liquids such as turpentine, benzene, benzole, benzine, gasoline, etc., for use in gas engines or for lighting purposes, in which connection should be mentioned such pioneers as Badt, Benz, Boulton, Butler, Clerk, Daimler, Deboutville, Etève, Gardie, Harrison, Hearson, Keith, Lambrigo, Monckton, Nash, Riotte, Roots, Sack, Samuel, Stuart, Freeton, Turnbull, Wordsworth, Wright, etc. There were also many inventions in connection with apparatus for generating carburetted air (known as air gas) for lighting purposes, in which air is intimately mixed with petrol, benzine, *essence de pétrole*, or gasoline, in definite proportion, and being thus "fully saturated" and consequently inexplosive, can be piped to house burners and used for lighting and heating with safety.

For the reasons stated, surface carburettors have long since been superseded by various adaptations of a form of inspirator first introduced by the writer in 1887 (15598) on his motor tricar, and in an improved form two years later (9203) in combination with an auxiliary cistern in which the benzoline as used then was maintained at constant level by a float-controlled supply valve for stationary and marine purposes. The last surviving surface carburettor was the Lanchester, this, which was adapted especially for automobile motors, consisted of a shallow chamber containing a series of wicks, in which the petrol supply was maintained at a constant level by a float-controlled valve, and the carburetted air generated by aspiration

mixed with a variable supplementary supply before passing on to the speed throttle of the motor.

One of the most notable surface carburettors was that used on the Daimler belt-driven benzine motor cars brought over here during the first few years after the Repeal of the Highways Locomotive Act (1896). In this, shown in fig. 1, it will be seen that benzine was run into a small cylindrical cistern containing a float-sustained perforated cone which carried an air inlet tube extending up within a second tube, forming part of a divided air and vapour chamber arranged over the benzine cistern below. The lower compartment of this cistern was connected by a pipe to a mixing plug and thence to the motor, as shown. Air slightly warmed, to compensate for loss of temperature in evaporation, entered by the pipe, marked "hot air," and was drawn down the suspended tube, whence it issued by a series of holes below the level of the *liquid*, and in thus rising to the surface in a stream of bubbles, carried up vapour in suspension; this richly-charged mixture was then diluted by a supplementary supply of air, varying in proportion according to temperature, speed, and other factors, before passing on to the motor throttle.

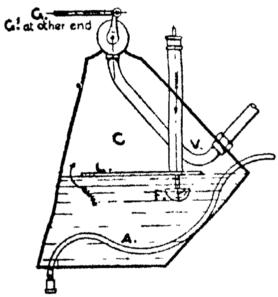


FIG. 2.—De Dion surface carburettor

Fig. 2 is another example adapted more especially for small motors; this was designed to fit between the tubular frame stays of De Dion motor tricycles, of which there were a great number in use during the years 1895–1905. Into this obloid chamber petrol was fed at intervals from a cylindrical tank to maintain the petrol supply at about the level indicated. Air drawn down the tube carrying the float, F, was deflected by the plate, L, over the surface of the "essence"; the resulting air gas was then drawn off through the double-plug throttle, G, G', by the pipe, V, to the motor, one end of the throttle serving to control the air gas and the other a supply of supplementary air, each being separately connected up to the front of the tricycle

by a rod and lever. A small tube, A, is provided to maintain the "essence" at the required temperature, this being connected up to the exhaust. As would be supposed, this form of carburettor was very variable in action and required some experience and skill to manipulate the controls to the best advantage, being subject alike to the effects of road surface, speed, temperature, quality, and time of renewal of the fuel charge. Apart from these drawbacks it was simple, and with care and some skill surprisingly workable, provided the motor spirit obtainable registered a density not lower than 700, and that the residuum was drawn off and the supply renewed before starting cold after a run

Compressed-Air Atomiser Carburettors.—*Class 2.*—Spraying by compressed air is a much more scientific method, but unadaptable for small motors owing to the considerable mechanism involved, as will be seen by reference to the example shown in Chapter V., where it is shown adapted as a paraffin vaporiser for a stationary engine. In its simplest form, as first introduced by Etève, the pioneer of this system, in 1881, there is an air pump, a pressure fuel tank, a spraying nozzle, and a volatilising chamber required, but as this lends itself to supplying multiple-cylinder engines, the complication so obvious with a single cylinder is thus proportionately reduced. The fault, however, as a petrol carburettor is in being too perfect—it does more than necessary, also the volatilising chamber is between the air and fuel-control valves, consequently the speed of the engine is not so instantly under control as when fitted with a carburettor having the mixture throttle on the motor side of the vaporiser. But its greatest drawback is its cost, and for this reason alone it would in any case have fallen into disuse with the perfecting of the "induction carburettor" for all motors run on petrol or paraffin, although in the atomisation of heavy residuum oils, as used in large-power injection engines, the use of a compressed-air blast at very high pressure has been found to have a compensating advantage.

Fuel-Pump Atomiser Carburettors.—*Class 3.*—The direct injection of the fuel in the form of a spray has many advantages in large-power engines, but has many disadvantages in small high-speed engines, and for petrol has no compensating factor

whatever. With an ordinary pump plunger the action is never precise, and is always leaky. These faults were first realised by Spiel, who, commencing in 1881 with a drip feed to the air inlet with benzine, then tried a cam and spring-plunger spray injector, but soon discarded this owing to the uncertainty of the pump valves, this being partly due to the low density of the fuel and partly to the necessity for supplying the fuel to the inlet of the pump at a constant level. This pioneer then adopted a plunger pump with mechanically controlled suction and delivery valves, both of which, P, P′, fig. 3, were actuated by a spring lever and stem, V, from a cam lever pin, N, against the pressure of a stiff spring in the delivery chamber, F. In action, when the pin, N, was pressed down, as on the admission stroke of the engine, the suction valve, P, would be closed firmly against its seat, and the delivery valve, P′, opened by the rod, V, the contents of the pump would then be sprayed against the incoming air at X, and be drawn together into the cylinder down the pipe, H. However, in engines fitted on this injection system difficulty was found in maintaining the exact proportion of spirit required for a uniform efficiency at slightly varying speeds of the engine, or with varying levels in the supply cistern; also owing to unavoidable solids carried in with the fuel, to leakage, or to loss of motion to the pump plunger. To obtain the best result, the volume of liquid injection should be approximately 1 to 10,000 of air, and a proportion of 1 to 9000 not only results in 10 per cent. higher consumption, but reduces the power of the engine; also a considerable falling off in the

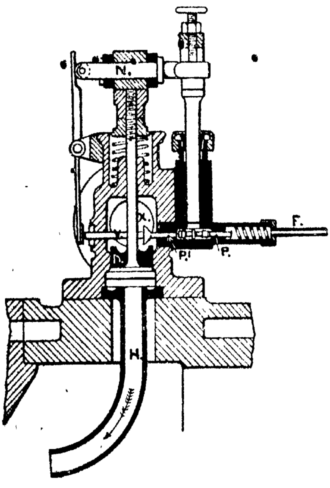


FIG. 3.—Spiel cam pump spray injection carburettor

power is noticeable when the feed falls 15 to 20 per cent. below the critical rate of injection necessary to obtain the best result,—much more, in fact, than any gain in economy due to the reduced rate of feed. So sensitive, in fact, were these engines, that frequent readjustment was generally necessary to compensate for either a varying level in the supply tank, or for minute differences in the operating mechanism; so much so, that it was the exception rather than the rule for any two engines of equal size to be adjusted to run through a brake test with uniform results.[1]

In the endeavour to improve on the cam-actuated plunger, many mechanically operated measuring devices have been projected, and in several instances applied, but with indifferent results. Obviously, the smaller the cylinder and higher the speed the more difficult is this problem. Some of the alternative methods that have not been the success anticipated include: all forms of recessed wheel valves, sliding displacer rods, syphons, cups, etc. Leakage past the plunger gland may be prevented by arranging for an overlay of glycerine, or castor oil, these two liquids not readily mixing with mineral spirit. Again, a diaphragm displacer, while being proof against leakage, must have valves. Then again, all such devices depend on perfectly constructed mechanism and very careful and adaptable adjustments; therefore for high-speed motors with cylinders in multiple they are peculiarly ill-adapted The case is aggravated when required to be run automatically under speed control, when the feed of an injection plunger must be either governed by (1) varying the stroke, (2) by controlling the fuel injection after leaving the pump, or (3) by arresting the action of the pump. Any of these methods are feasible, but involve multiplicity of parts; moreover, the injection for each cylinder must be separately adjusted. However, plunger injection carburetion is still used on many single-cylinder gasoline engines of American construction, and has actually been tried on high-speed engines with multiple cylinders, as in the Adams-Farwell motor with revolving cylinders, and on some of the earlier motors used by the Brothers Wright on their pioneer aeroplanes. What extreme niceness is

[1] This was in part due to the slide-flame-pocket-ignition valve used in these engines.

exacted according to this method of carburetion will be recognised on considering that a 4-in. × 5-in. cylinder will require a plunger not larger than 0·2-in. diam. × 0·25-in. stroke, for which the range of stroke to produce a mixture varying from 1 in 9000 to 1 in 12,000 is 0·06 in. In the endeavour to adapt the plunger-injection principle to a mixture throttle-controlled engine, the author designed and patented two forms of pulsator carburettors, 1780 and 1781 (1888), one of these, illustrated in fig. 4, was for

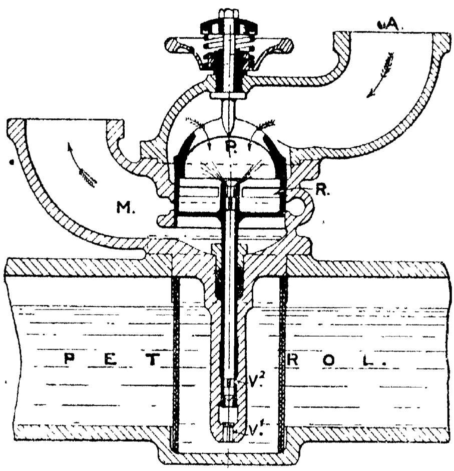


FIG. 4.—Butler's variable stroke induction-action pump carburettor for benzoline vertical two cylinder engine—1888.

a two-cylinder vertical 7-in × 8-in. engine, running normally at 280 revs., but had an extreme range from 200 to 360 r.p.m. The pulsator in this carburettor had a combined piston and hollow plunger, P, the latter, 0·375 in. diam., worked in an immersed barrel with a foot-valve, V¹, a second spraying valve, V², having a stem extending the full length of the hollow plunger served for the delivery. The range of stroke was approximately 0·12 in. to 0·35 in., according to throttle opening, tension, and position of the regulator controlling the pulsation of the piston. Air entered at A during the admission strokes of the engine, the

piston being drawn down by suction effect until the ports, B, registered in varying degree with corresponding ports in the casing, the air in its passage through the piston thus met the issuing spray, and continued as mixture *via* the outlet arm, M, to the throttle.

Some years later a modified form of pulsator carburettor was tried on a two-cylinder car motor (fig. 5) and worked as in the preceding example by varying the petrol injection by a hollow plunger, R, actuated by the direct action of the air flow past a disc, D. In this there were peculiar features, the mixture to the motor, for instance, was controlled by the combined action of a spring and hand regulator lever, S, connected to a cam, M, thus limiting the opening of the valve, V, which was held in a floating position by two springs held by a clip extending inwards from a sleeve surrounding the slanting slot, A. The plunger, R, of the barrel, P, drew direct from the float cistern, F. The disc-actuated plunger, D, R, obtained its action partly by back flow; a fibre buffer, B, was thus provided to soften the action of the down or injection stroke. The injection plunger is entirely independent of spring recoil, being drawn up by suction effect to an extent varying as the throttling action of the valve, V, and is forced down sharply by momentum recoil of the air-flow.

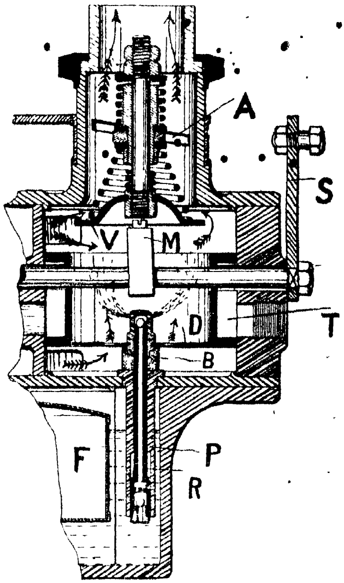


FIG. 5.—Argyle variable-stroke induction-action carburettor for two cylinder petrol motor.

This principle of utilising recoil action is illustrated in another manner in the diaphragm-injection carburettor (fig. 6).

In this example a corrugated flexible disc, F, takes the place of the plunger, and is extremely simple and withal capable to a certain extent of a variable feed in proportion to the throttle opening. In action the slight suction effect during the admission stroke draws down the diaphragm, and with it the spray nozzle away from the ball-pointed feed regulator, petrol then flows in by a head feed at P, when on the closing of the motor-admission valve the back flow of the mixture, together with the reaction of the corrugated disc, causes this to spring back and force out a charge of petrol past the nozzle in proportion to the pulsating effect of the mixture flow, there is really no valve required provided the regulator is adjusted to close the outlet above the nozzle. Its action therefore, is automatic, and with a nozzle aperture to give the exact jet required, has points ahead of a plunger feed for a single- or double-cylinder high speed motor working under throttle control. There is a dish below the choke tube to collect drip, and this

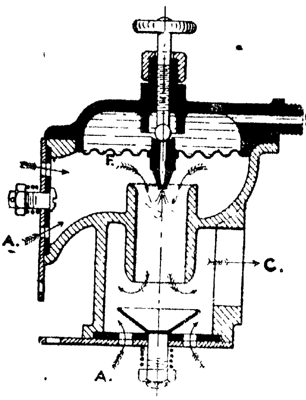


FIG 6.—Injection carburettor with air-pressure controlled diaphragm feed Blake.

suggests the need for an indexed stop valve at P, moreover, the design does not lend itself to the ready removal of the jet nozzle, nor for any feasible method for regulating the outflow as by a pin deflector, so commonly used to vary the feed of single-jet induction carburettors.

Gravitation-Feed Atomiser Carburettors.—*Class 4.*—This method—when used in conjunction with a mechanically operated timing valve, and provided the engine is required to run at a fairly constant speed—has given quite satisfactory results; carburettors of this type are used in many small stationary and marine engines, and extensively in gasoline motors of American construction, their cost of manufacture being com-

paratively low and their action simple. There are however some objections to their application in cases where absolute automatic and self adapting carburetion is desirable, such as liability to flooding on stopping of the motor and incapacity for variations of speed, moreover, carburettors of this type do not generally speaking, possess that nicety of adjustment and control necessary for a high-class high-speed petrol motor.

The Pennington engine was worked on a hand-controlled gravitation feed. Gravitation-feed carburettors when provided with a non-return fuel valve to the atomiser nozzle so as automatically to control the feed, through the agency of an air piston or valve—give fairly satisfactory results in stationary and marine engines, and can be made to work tolerably well on some slow-speed car motors. In these cases the carburettor is provided with an adjustable petrol feed and air and mixture supply, each being arranged directly under the control of an intelligent driver. There have been some dozens of modified designs of gravitation-feed carburettors of which the four varieties illustrated by figs. 7 to 10 are typical examples.

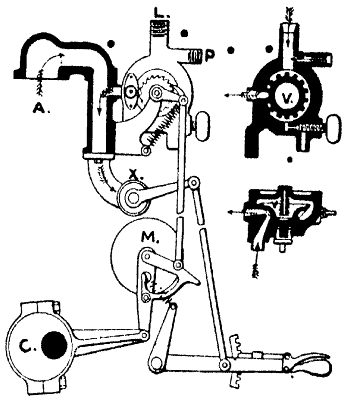


FIG. 7.—Cup wheel gravity feed carburettor with trip action combined ratchet and throttle control—Gobron Brillie.

Other carburettors included under this class are the Aigle, Alderson, Aris, Blake, Constantine, Dalifol, De Sales, Dupuy, Endurance, Forman, Gautière-Wehrlé, Grove, Hully, Iden Richeur, Kulstein, Lepape, Lucas, New, Oldsmobile, Pennington, Roubeau, Star, Strelinger, Tourand, Union, Wolverine, etc. etc. All these show a marked similarity, and are nearly all provided with an induction or cam-operated feed, in combination with hand-controlled petrol, air, and mixture valves.

Of these the Aris is the most suitable for a variable speed motor, as it is designed to regulate the air-flow with the injection simultaneously.

The description of the Gobron-Brillie cup-wheel gravity-feed carburettor (fig. 7) is as follows:—This was designed for the use of methylated alcohol, and for that purpose was provided with a supplementary petrol-feed connection, P, on the cup-wheel casing, alcohol entering at L, after the motor had run a few minutes to warm up. Air entered at A, and mixed with the spirit in a throat, as shown; the mixture then passed through a throttle, X connected up so to be under synchronous control with the mechanism actuating the cup wheel, V. This was obtained through an eccentric, C, on the cam shaft, which actuated a rocker, M, carrying a tumbler inertia action "hit-or-miss" governor: thus the feed wheel, V, received an intermittent motion through a ratchet disc and pawl connected to the tumbler governor on M. The speed could be held under control by the adjustment of a hand lever and quadrant, which simultaneously tightened or slackened a spring on the governor catch-block and opened, or closed, the throttle.

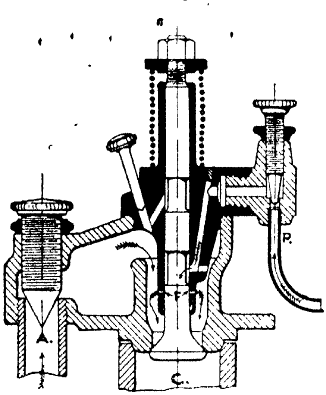


FIG. 8.—Gravity action snifting-valve carburettor (Crossley Hulley).

The gravity-feed carburettor shown in fig. 8 is one of a number of variations of a class of snifting valves in which the opening of the air-admission valve by suction effect allows petrol to stream in with the air. In this case the petrol, to a certain extent, is fed in measured charges, being first fed to an annulus formed by the valve stem, which on being pulled down by suction effect is brought to register with a series of holes, E, the petrol thence mixing with air entering at A to the admission valve, C. This carburettor is not adapted for

an automobile, nor any motor working under throttle control, being designed for small stationary petrol motors having a "cut-out" governing mechanism on the exhaust-valve lever.

The gravity shifting-feed carburettor shown in fig. 9 is another variant of the same class designed for a high-speed motor, but for reasons pointed out has, together with a number of others, fallen into disuse for automobile work wherewith automatic action is so desirable. In this the petrol is fed by a tube, P, from an overhead tank under control of an adjustable pin valve, whence the charge is fed into the mixing chamber on the admission stroke of the motor by the downward movement of the hollow piston valve, V, carrying with it a stem normally closing the petrol inlet. Air enters at A, also in controllable quantity, through a shutter flue below the piston; the branch, X, leads to the admission valve of the cylinder, and E to the exhaust.

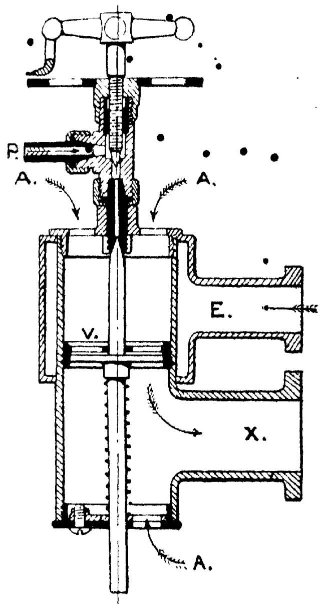


FIG. 9.—Gravity carburettor with throttle-controlled shifting feed - Endurance.

This carburettor is not adapted for a great range of speed control, and is only suitable for a single-, or at most a double-, cylinder motor under immediate hand control by the index-pointer regulator; thus, as pointed out, the correct mixture can only be obtained by readjustment for any variation of speed, and is quite unsuitable for a road-car motor, although for a motor boat, where the speed is constant and the carburettor in full view, fairly satisfactory running

under conditions where automatic action is not a desideratum, can be obtained.

The 'gravity-feed' carburettor illustrated in fig. 10 was specially designed for automobile use—*i.e.* in connection with a motor governed by a "cut-out" action on the mixture supply. In this example, petrol, under a head sufficient to force it past a pin valve enters at P, on the opening of the feed valve at the bottom of the spray nozzle, this being simultaneous with that of the mixture valve to the motor inlet port, C, as by the rod, F, and rocker shown interconnected. The degree of opening of the petrol valve in this instance could be varied by the adjustment of a sleeve block having a slanting slot, also, the air supply could be varied by an adjustable shutter, and in both cases from the car seat; thus this carburettor fulfilled the conditions required in the days when "cut-out" speed control with tube ignition was the vogue (1896–1900), provided they were skilfully handled

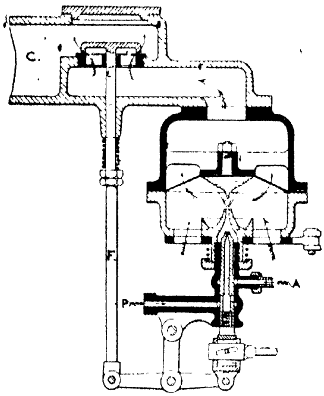


FIG 10.—Gravity-action jet carburettor with air-controlled feed Iden

CHAPTER III

AUTOMATIC AND HAND-CONTROLLED INDUCTION JET ATOMISER CARBURETTORS, WITH CONSTANT LEVEL-FEED CISTERNS.

Class 5. As in the case of the Giffard injector for projecting water into boilers by momentum effect derived from steam (which for many years was considered by locomotive engineers generally as unreliable and by many as quite unfeasible), so with the introduction of road cars demanding a more perfected form of motor the inspirative principle of utilising the induction effect of the air-flow first introduced by the author in 1887 was not generally adopted until some twelve years later, when unfortunately for the inventor, one of the most valuable of the improvements patented in this country, as well as in four European countries and in America, had been allowed to become public property, notwithstanding that the U.S.A. fees were paid up for the full term of seventeen years, the regulations then in force in that country allowing a patent to automatically terminate on the lapsing of the patent in the country applied from. Although this loss at that time was not considered of very great importance, later events proved it to have a far-reaching effect on the automobile industry, for, according to the decision on the famous "Carburettor Patent Case" fought out in 1901 by the British Motor Traction Company *versus* the Automobile Mutual Protection Association, one of the author's patents (9203, 1889), which had been allowed to lapse in this and five other countries, was held on behalf of the M.P.A. to anticipate a more recent patent (5990, 1890) applied for by the author, and then still in force, which was owned, together with

the Maybach patent (16072, 1893), by the M.T.C. In this connection it is only right to state here that the author's carburettor had been already in use on marine and stationary engines since 1889, referring to which, Justice Farwell, under whom the case was tried, said "In this case it has been proved that Butler will work, and will work as well as, if not better, than any other"; also that Mr S. F Edge, in a letter to the *Autocar* of March 14, 1903, wrote that "It is well that everyone should remember that the English Law Courts have held that the Universal float-feed type of carburettor—without which nine-tenths of the present day motor carriages do not run—was invented and patented by Edward Butler, an Englishman." The effect of this decision on the automobile industry up to 1903, the year the "1889" master patent would have lapsed if fully paid up, meant a difference of some £50,000, calculated on a 5 per cent. basis, on a million pounds worth of road and other motors estimated to have been in use in this country up to that date, 1903 In proof of the practicability of the author's carburettor, one was constructed to the exact design contained in the 9203 (1889) specification, and run from 70 to 100 miles on a car by Mr W H. Astell, manager of the New Orleans Motor Company (on behalf of the M P.A), who had driven a car in the 1000 miles trial, and had won four prizes for driving. He said in evidence That he had tried the Butler carburettor, and considered it was the best he had seen on any car. That from a practical motor-car driver's point of view he did not think it mattered where the exact level of the liquid was in the pipe, the whole secret of the problem was to keep the liquid always at one constant level.

This improved form of carburettor, which consists of a combination of atomiser nozzle supplied with petrol from a small cistern—where it is maintained at a constant level by a float-regulated feed, and therefrom projected in the form of a fine spray into a mixing chamber in consonance with the pumping action of the motor piston,—has survived all other methods and is now, in slightly and variously modified forms, in universal use in all makes and types of petrol-spirit motors, whether for use on land, water, road-car, or for aero-craft motors. The reason for this is its simplicity, and, when properly and scien-

tifically constructed, its absolute automatic action over a wide range of speeds, even under the very trying conditions obtaining in a motor exposed to changing levels, tilts, and jolts, as experienced in a fast automobile results so far impossible to obtain by any other means This is conclusively proved in the next chapter

The first application of a carburettor based on the jet-induction or inspirative principle was made by the author on a petrol tri-car, made in 1887 88, the first made in this country. This car had two cylinders 2 25-in. diam × 5-in. stroke, the ignition being by a single high-tension spark coil and rotary distributor, as now universally used on all high-tension magnetos. From the author's experience with surface, pump-injection, and drip feed carburettors, none of which were adaptable to a motor to be run at a varying speed—as each of these methods required considerable nursing under trifling changes in running conditions - an entirely new method, as illustrated in fig. 11 had to be used. This instrument, designed to work on the inspirative principle, was placed in a dust-proof box over a shallow circular cistern holding about a gallon of benzoline. This spraying device, known then as an inspirator, had a vena-contracta throat now known as the choke tube or venturis. Surrounding the neck of this throat there was an annular space into which the fuel feed was drawn past a hollow screw-down valve having a close fitting fine thread (40 per in.). To equalise the induction effect of the air-flow at varying speeds of the motor and throttle opening a pulsator was fitted in the throat of the air nozzle having a free movement against the tension of an adjustable spring, as shown, by this means the feed was so automatically regulated in proportion to the air as to enable the motor to be controlled entirely by the mixture throttle, within a range of speeds from 200 to 600 r.p.m. on the level, without any adjustment of the benzoline feed or the pulsator plug In practice, however, it was found that a slight adjustment was necessary to the feed from time to time with a falling level in the cistern (2 in. deep), to minimise the effect of which the inspirator was arranged to draw from a well about three times the depth of the cistern, thus reducing the difference in suction effect required and compensating for

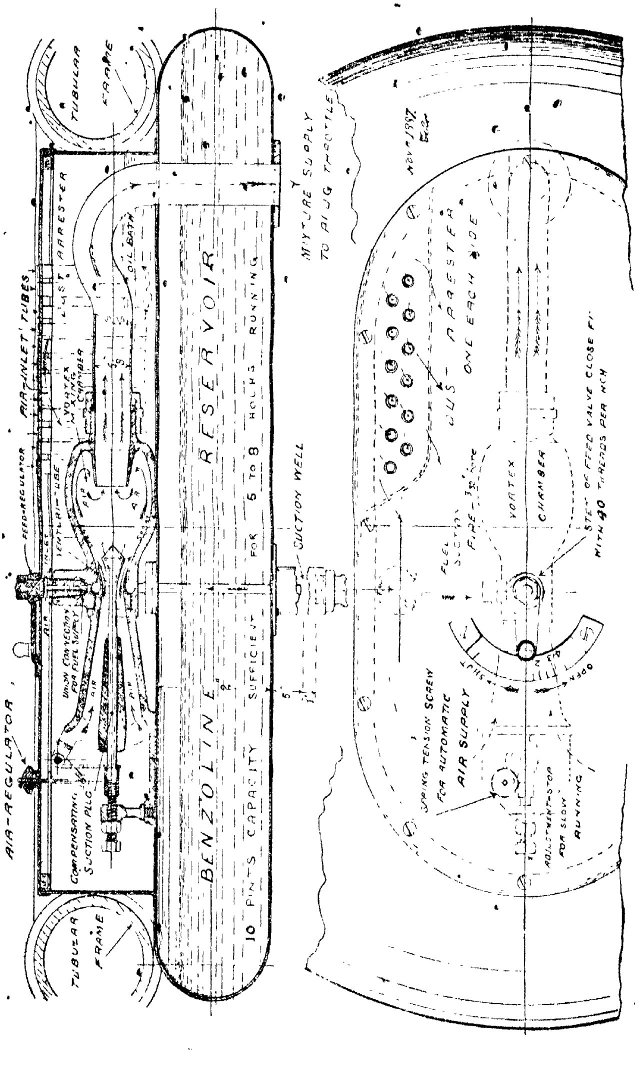


FIG. 11.—Induction-spray carburettor with automatic air control, as used on the Butler petrol tri-car—1887–88.

the effect of tilt; this also ensured the exclusion of air to the feed tube when running with the cistern nearly empty. The feed valve was proportioned to require an opening of 0·006 in., *i.e.*, such as obtained by a quarter turn of the screw-down valve, the necessary variation, more or less than this, never exceeding 15°; and to make the feed adjustment quite definite in either direction, any slack of the finely threaded screw was taken up by a spring. The air supplied to the carburettor was drawn down a series of small tubes dipping in a bath of lubricating oil as shown, this being done for the purpose of excluding dust and floating matter from the cylinders, and although quite unnecessary in this case there is no question about the advantage of an effective dust excluder for automobiles when exposed to the abrasive action of dusty roads. In proof of the efficacy of an appliance of this sort a modified application has been adopted in the Ford petrol-paraffin field tractor.

The only fault in the induction-jet carburettor as made for the author's two-cylinder petrol tri-car, when applied for engines required to keep running under governor control for long periods, was the effect of varying level on the feed. This he remedied in the carburettor shown in fig. 12, two years later, by the addition of a small cistern containing a hinged copper float, *f*, which on falling raised a check valve against a spring and the head pressure of the liquid from the main supply tank, which may be situated in any convenient position, as long as it is high enough to overcome friction in the service pipe, *p*. It is important that the check valve should have a moderately stiff spring, sufficient to ensure its closing against any obstruction that may be caused by grit, fibre, or any floating matter coming over with the liquid; the valve, further, has a sharp seat on to which it is essential that it should be ground an exact fit. In fig. 12, the constant-level cistern, *k*, is shown forming part of the base of a 7-in. × 8-in. three cylinder vertical benzoline engine made for a river boat. Warmed air is supplied by the pipe, *a*, which in flowing through the "venturi" or vena-contracta nozzle, *n*, is accelerated to a velocity of 900 to 1200 feet per second. This high velocity causes a "depression," varying according to throttle opening, from 1 to ½ in. in the annulus surrounding the nozzle, due to induction (as determined by a gauge) in

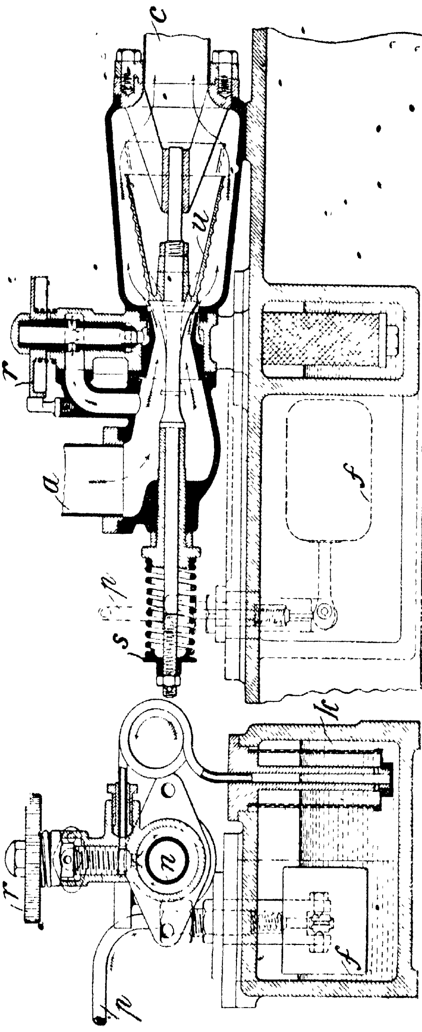


FIG 12.—Float-feed induction carburettor for three-cylinder 7 in. × 8-in. launch benzine engine, 1889.—Butler.

excess of that in the mixing chamber. The spray feed is regulated by the screw regulator, r, and is atomised by a central air jet; the stem of the feed regulator is cut with a very fine close-fitting thread (40 per in.) and provided with a graduated milled disc and pointer to determine the exact opening required, which varies from one-fourth to one-third of a turn. The supply of air from a is controlled at varying degrees of throttle opening and speeds of the motor by the pulsating air-plug, u, which moves in the direction of the current (as shown in dotted lines) for a distance proportionate to the varying speed of the motor pistons and throttle opening. Thus by increasing the air-way through the nozzle, this action corrects the tendency to draw in too much spray at "full throttle." When the motor is required to run "slowed down," the spring, s, pulls the plug towards the nozzle, thus causing the necessary inductive effect to maintain the mixture flow to the supply pipe, c, at a sufficiently constant degree of carburetion to permit of regular running without mis-fires for long periods, and ensures instant acceleration on again opening wide the throttle. No foot valve is required at the bottom of the suction tube, for the reason that the feed regulator, when closed, seals the delivery end, and in running the film between the conical end of the valve and its seat, which is only 0·0006 in. in thickness, has sufficient tension to prevent any falling of level in the suction tube, however slow the engine may be running; moreover, this film does not break or evaporate during a short stop, although in usual practice, to facilitate re-starting, the feed regulator is closed when stopping the engine. This same form of carburettor has been used in stationary, horizontal, and vertical engines varying in size from a 1·5-in. to an 18-in. diam. cylinder, the same form of feed regulator, pulsator, and mixing chamber being used in all. This design of carburettor, moreover, lends itself for a double, or even a triple, feed—*i.e.* for a petrol-started paraffin or gas-oil engine, with water feed; also for a combined town-gas and producer-gas engine, the town gas being used to start on, or as an alternative fuel. This form of carburettor has, further, been in many cases adapted to enable an engine to run on paraffin or town gas, also to "start" on petrol, and then either "continue" on producer gas or intermediate semi-refined oil.

Engines so fitted are interchangeable while running from gas to oil, or *vice versa*.

In fig. 12A the mixing chamber was formed to cause the mixture to acquire a vortex motion, this being found to work more effectively than any arrangement of ridges or baffles, such as shown on the pulsator cone in fig. 12. The reason for this can be explained as resulting from the reduced obstruction to mixture flow; the pulsator was also cut down in size and weight to a simple conoidal cone, a form adopted in all subsequent carburettors for petrol, gas, or oil engines of the author's design.

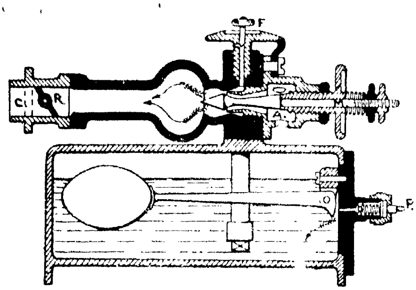


FIG. 12A.—Butler float feed induction carburettor with automatic air control, made in 1889-90, for 2 in. × 4-in. domestic motor.

In this application air was drawn at A direct; benzoline supplied at P, by a copper tube 0·125 in. diam., was maintained at constant level by a copper float at the end of a long arm, the hinged end being provided with a cam that impinged against the stem guide of a check valve held up to its seat by a stiff spring. The mixture was controlled by an ordinary throttle, R, and then passed on through the connection, C, to a jacket chamber (2 in. deep) around the cylinder. This motor could be run at any speed between 300 and 1200 r.p.m., according to throttle opening. Once adjusted, it was not necessary to alter either the feed regulator, F, or pulsator adjustment, M. The motor would have worked with a freer action if the float cistern had been arranged at one side and higher up to the level of the inlet, as naturally adopted where there is a free choice; but in this case it was desired to arrange both carburettor and

feed cistern within the frame of the motor. The induction effect of the venturi air nozzle and annular jet feed is much greater than produced by a central jet; indeed, several engines have been arranged to draw direct from a base tank in which the level of the paraffin varies from 12 in to 18 in below the inlet to the feed regulator.

A constant level can be obtained in a feed cistern constructed on the bird-fountain principle, and has been so used on some paraffin engines and in a number of lubricators. A constant level can also be maintained in the feed cistern by utilising the suction effect of the air-flow, as in a pulsator pump, with suction and delivery valves, a method used in an early form of the Olds carburettor.

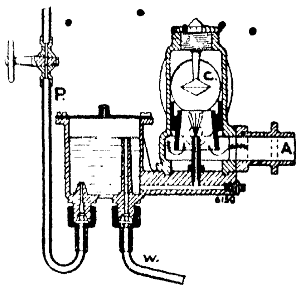


FIG. 13.—Spray induction carburettor with a constant level obtained by an overflow feed—Craig.

There is another method that has been tried, known as "Griffin's diaphragm feed." This consists of a circular shallow cistern having a corrugated diaphragm the rise of which, by means of a lever connection, opens a check valve controlling the feed from an overhead supply tank, which is again closed in the same manner, when the liquid running into the cistern attains a predetermined level. The objection to this is the effect of vibration and to the limited movement due to small differences of level and weight of the liquid in the cistern, thus requiring a very fine adjustment and sensitive diaphragm. Another method is the "overflow feed" (fig. 13). In this, petrol is supplied from an overhead tank by the pipe, P, to the feed cistern, in which there is an overflow pipe or weir connected to a return pipe, W, leading either to a sump from which the surplus feed is pumped back again to the overhead tank, or the petrol may be pumped direct from the main tank to the overflow constant-level-feed cistern as used in supplying petrol to many of the high-power aeroplane motors. This is a method more suitable for large-

power stationary and marine engines arranged to run on either paraffin or semi-refined oil.

From experience gained by much trial and error, however, it has been conclusively established that there is so far no successful substitute to one or other of the several forms of float-feed cisterns, now universally used in petrol and petrol-paraffin motors for all but very exceptional purposes. These consist either of (1) a hinged metal float, as illustrated in figs 12, 12A, (2) a hinged cork float, as shown in figs 31, 35, 41, (3) with a plain unbalanced cylindrical float and under feed, as shown in fig. 27; (4) with a balanced form of cylindrical float, having the feed-valve on the under side, as shown in figs 14 18, 22 25, 26, 30, 32, 33, 34, (5) with float arranged concentrically as shown in figs. 14, 28, 32, 35, or as (6) with a simple cylindrical direct-action float with feed-valve in the cover, as shown in figs 20, 39.

In connection with each of the several methods for maintaining a constant level, some form of single, double or multiple jet atomiser is used, of which the most general is a plain nozzle having an aperture varying from 1 to 2 millimetres in diameter, others are either annular, or in effect annular, as when fitted with a needle-valve regulator. In addition to the illustrated examples in this chapter of the earlier forms of jet-atomiser carburettors having float-feed constant level cisterns (mostly for automobile motors) may be mentioned others, such as the Abeille, Ader, Brooke, Butler, Cail, Charly, Cottereu, Crouan, Daimler, Dorey, Dunlop, De Dietrich, De Dion-Bouton, Eldin, Espinesse, Fillet, George-Richard, Goutallier, Jenatzy-Martini, Kreb, Le Blon, Longuemare, Martha, Maybach, Mors, Napier, Ormonde, Peugeot, Phœnix, Sanson, Sthenos, Vaurs, Wilkinson, and others. It would serve no useful purpose, however, to give illustrations of many of these, owing to their similarity of construction to the examples of this class of carburettor illustrated.

Perfect Carburetion essential to wide range of Speed Control.—The very perfect speed control of some of the modern petrol multi-cylinder motors is obtained partly by an adjustable ignition and a graduated throttle, but is principally dependent on a self-adapting form of carburettor which will automatically and definitely carburete the air to form a mixture of an exactly

predetermined degree under all conditions of temperature, load, and speed. To obtain this result a constant level must be maintained in the supply cistern, which in the De Dion engine (fig. 14) is made to surround the atomiser jet so as to be entirely independent of the road gradient or camber. In this example the float is annular and surrounds the jet and choke tube, and is of the balanced type with under-feed at P. The choke tube forms part of the combined air and mixture regulator, R, which receives a part rotary motion from the control lever, thus simultaneously adjusting the air supply to the throttle opening, no automatic valve being used.

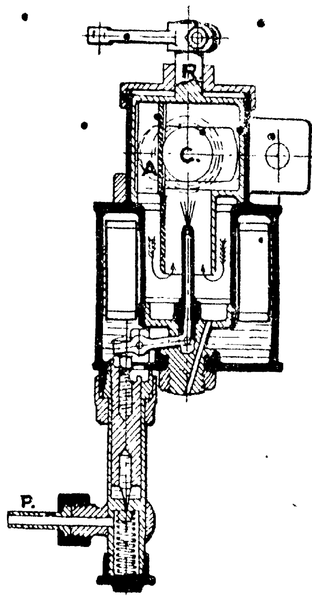


FIG. 14.—Central feed carburettor with annular float—De Dion.

The degree of induced suction caused by a variable flow of the air supply must be modified by an automatic air plug or its equivalent, so as to adjust the sectional area of the air nozzle in proportion to the current velocity of explosive mixture to the motor cylinder. This can be effected in a variety of ways, which will be referred to more particularly in the next chapter. But during the period 1896–1906, or so, the most generally adopted method was the automatic supplementary air valve, another, as described above (fig. 14), was to simultaneously adjust the air to the mixture supply, still another, to adjust both air and petrol to the mixture supply by hand, as in the carburettor illustrated in fig. 19; or, as in many carburettors now in use, an automatic effect is produced by means of a movable air plug,

such as A in fig. 15, thus correcting the sectional area of the air nozzle so as to obtain the necessary suction effect on the petrol nozzle, U, to ensure a working mixture at fast and slow speeds.

A method very frequently employed consists of the simple addition of a supplementary air valve, this valve opening against the resistance of a spring and admitting air to the carburettor usually at a point between the petrol nozzle and the throttle, as shown in figs 17, 21 In this manner ordinary non-automatic carburettors can be quite easily converted to work with a fair range of speed in the automatic manner, provided the motor has been tuned up by the necessary adjustment of the air supplies, valve springs, etc. Another form of carburettor working on this principle is illustrated by fig. 16. In this instance the automatic air valve is behind the petrol nozzle the effect being very similar whether the extra air at high speeds is added before or behind the petrol spraying nozzle. In this known as Brooke's carburettor, there was an automatic speed piston throttle regulater, P, normally held in position by a spring resting against the plunger, H. On the motor tending to race the increased suction effect drew down the rubber diaphragm, D, and with it the piston, P, thus closing the supply ports to a degree depending on the speed of the motor and the adjustment of the speed lever, L; while running slow the air valve, V, remained either quite closed or open a very little, the necessary air being supplied at A. This method of governing, however, has not proved the success anticipated, owing to the difficulty of providing a diaphragm combining sufficient strength with flexibility.

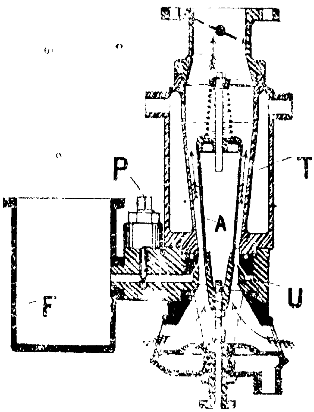


FIG 15.—Automatic carburettor with pulsator plug in venturi choke tube and annular petrol jet - Decauville

Automatic carburettors in various forms, from becoming more and more popular for the touring or service car, are now considered a necessity, judging from the number of the designs in use. One of the most extensively adopted methods was to vary the air resistance in one way or another, the Thornycroft, and Rover automatic carburettors illustrated in figs. 17 and 18, affording two typical examples of this kind, and, in both cases, by very similar means. In the first of these the air nozzle is

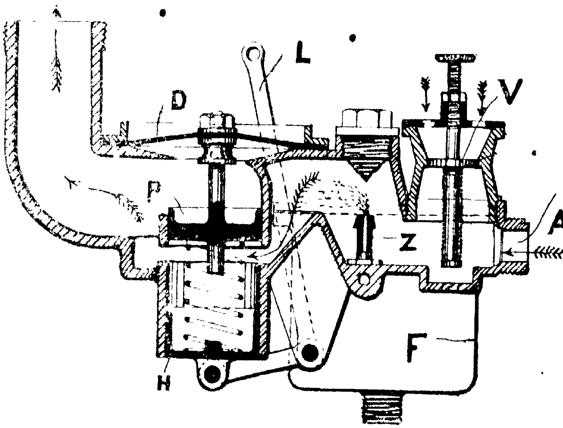


FIG. 16. Float feed jet carburettor with automatic air supply diaphragm-controlled mixture supply valves.—Brooke.

seen to be combined with a supplementary supply valve or piston which advanced to a degree depending on the speed of the motor. In the other also it will be seen that a very nearly identical effect can be obtained by the movement of the perforated air nozzle, C, together with the piston, P, thus bringing the openings shown at the arrows into communication with the interior of the throttle valve, E, to a greater or less extent, according to the speed of the motor. The movement of the piston, P, is automatically influenced by suction in the supply pipe. the movement in this case can be also controlled by hand through the rod, D, while in the other the action is entirely automatic.

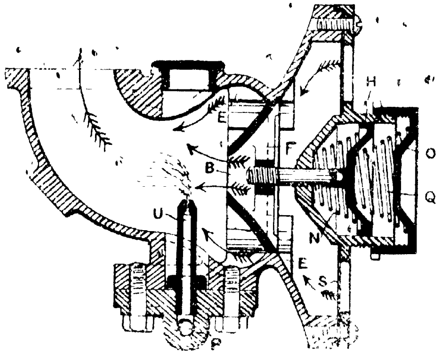


FIG. 17.—Induction-jet carburettor with sliding air nozzle and automatic air supply—Thornycroft.

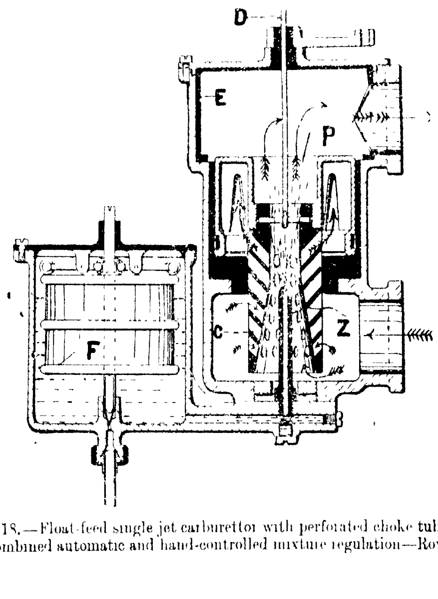


FIG. 18.—Float-feed single jet carburettor with perforated choke tube and combined automatic and hand-controlled mixture regulation—Rover.

In the Deasy automatic carburettor the mixture could be corrected by the upward movement of a perforated air nozzle formed somewhat as in fig. 20. The petrol nozzle in that case was, however, fitted with a plug connected up so as to be adjusted by hand as required. This method was also adopted in an earlier form of the Binks' carburettor (fig. 19). In this example the valve-coned head, G, was provided with multiple

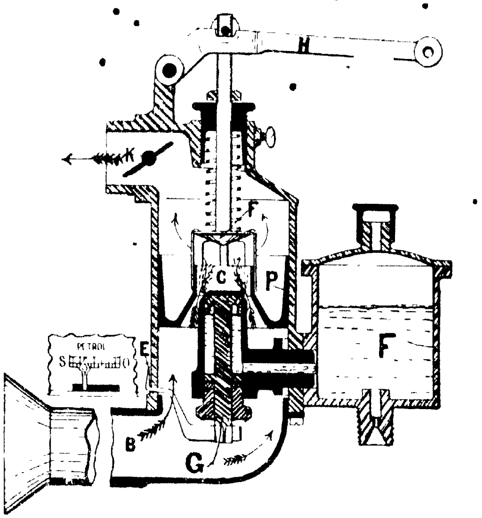


FIG. 19 – Multiple jet float-feed carburettor with automatic air control—Binks.

outlets which registered with openings in the nozzle and produced an effect somewhat analogous to that obtained in the Longuemare carburettor (fig. 20), only with the difference that the adjustment could be made automatic. The degree of suction on the petrol nozzle was corrected by the rise and fall of the air-nozzle piston, P, due to varying depression; the movement of this piston could also be hand-controlled through the stirrup, F, and lever, H.

In the Longuemare, which had a considerable vogue both for cars and cycles, there was a multiple-jet effect produced

by a grooved vee-headed plug, which lent itself for easy adjustment. In this carburettor (fig. 20) the extremely contracted neck in the choke tube was also a feature and caused an unusual depression. Its construction was extremely simple, having no automatic parts excepting the float, which was of the direct-action cover-fed variety, with long taper pin valve, P. Air

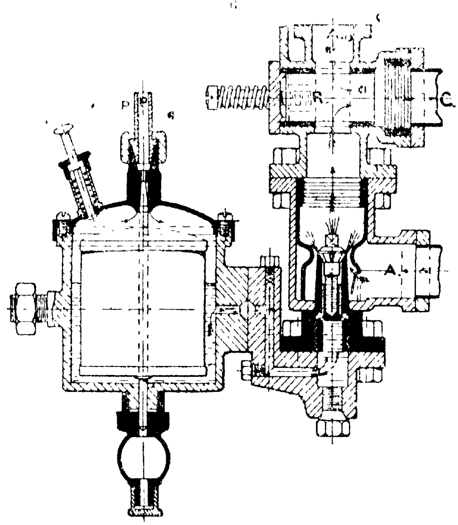


FIG. 20.—Multiple jet carburettor with combined supplementary air and mixture plug throttle—Longuemare.

entered at A, A, both being controlled by a double-ported throttle, R, to the supply pipe, C.

Economy and Super-Carburetion.—It is so easy to use more spirit than essential for the power developed in a petrol motor, that the importance of an automatically regulated carburettor—one that will give the critical degree of carburetion under all conditions of speed and load—cannot be too well appreciated.

As there is in petrol engines, for any given compression, a critical mixture which results in the highest explosive pressure, a very little deviation above or below this degree will result in

a greater proportionate difference of power developed for the quantity consumed. One may, with some carburettors, frequently super-carburete the mixture so that a smoky exhaust with a soot deposition in the igniter follows, resulting eventually in mis-ignitions and greatly increased inefficiency of working.

The motorist may be heard to blame the quality of the petrol he is using or at least this often used to be the case, but the fault, then as now, is more often due to the mismanagement of the motor by inexperienced adjustment of the carburant. An exactly graduated mixture with accurately timed electric ignition are essential factors in the working of a spirit motor and are of equal importance to large gas-tight admission exhaust valves and well-packed, perfectly balanced, and efficiently lubricated pistons.

Alcohol Carburettors.—The remarks on mineral spirit carburetion may generally be applied to alcohol spirit for use in petrol motors with this difference —viz. that alcohol is more expensive and less efficient (having a heat value approximately as 12 is to 20), but has an advantage over mineral spirit in tropical countries owing to there being fewer restrictions to transport. Some considerable encouragement has been given to the distillation of crude alcohol (on the Continent) from beet, potatoes, and grain to foster home agriculture, and many surprising results have been obtained in road cars propelled by alcohol motors. In the tropical sugar-growing countries, India and South America, where alcohol can be cheaply distilled, it may, by possessing similar properties to mineral motor spirit, become a serious competitor to petrol and paraffin motors. In the successful use of alcohol a higher compression in the cylinder is found necessary, which in turn would point to

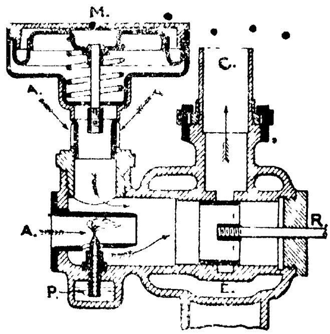


FIG. 21. Float feed jet carburettor with diaphragm controlled supplementary air and piston-mixture throttle—Kreb.

the advantage of a comparatively long stroke. The Gobron-Brillie double-piston engine, with a single-combustion chamber, favoured this view. The best results are obtained with a compression as high as 120 lb per sq in., and even higher can be used.

The carburettor used, whether it be a form of snifting-drip feed or constant-level feed, should be jacketed by an exhaust or hot-water chamber so that the comminuted spirit spray may be thoroughly volatilised and incorporated with the air supply The temperature of the mixture should not be raised above 300° Fahr., and to obtain the most economical results need not be higher than 200°, but, for facility in starting a separate feed of petrol spirit should be used for a minute or so.

In the use of benzole[1] the remarks on compression also apply, but to a less degree, and 90 lb. per sq. in., as against 60 lb. for petrol, can be continuously used on full load, without any detonating effect, in a properly designed motor

[1] Obtainable from most gasworks

CHAPTER IV.

CARBURETTORS CAPABLE OF AUTOMATICALLY ADJUSTING THE AIR AND PETROL SUPPLIES OVER A WIDE RANGE OF SPEED.

IN the modern automobile motor a demand has sprung up for a greater range of speed control, and in order to obtain this result more depends on the behaviour of the carburettor than on any other part of the motor. If the petrol in its liquid state, as used in all carburettors having a spraying nozzle, followed the same law as obtains in the flow of gases, no difficulty would be experienced in driving in an amount of spirit spray in proportion to the air supplied to the motor. In practice, however, owing to surface adhesion of the liquid, and partly to its capillary tension—especially when flowing between two surfaces, such as those formed by a feed valve in its seat or even by the very small apertures constituting the ordinary spraying nozzle,—the liquid petrol has a tendency to drag and cling to the metal surface of the nozzle. A comparatively large nozzle area has therefore to be used when the flow of air to the motor is reduced by throttling with correspondingly diminished suction effect, in order to ensure the necessary supply of spray.

Assuming the nozzle areas for both the petrol supply and air to be fixed, a carburettor so formed would be only suitable for supplying a perfect mixture to a motor running at one critical speed. By providing a supplementary air supply, however, a simple means is obtained whereby the suction effect on the petrol nozzle can be corrected for a considerable range of speed; other methods for the same purpose have been adopted in considerable number, as follows:—

(1) By admitting supplementary air to the mixture formed, in a carburettor having a non-automatically controlled jet, by means of a spring-loaded lift or piston valve, as shown in figs. 16 17, 21, 22, 24, 25, and 28.

(2) By admitting supplementary air by gravity-loaded ball, plug, plunger, or piston valves, as in figs 18, 19, 23, 25, 26, and 27.

(3) By augmenting or diminishing the area of the induction or choke tube, as in figs 10, 12, 12A 15, 18 19, and 44.

(4) By simultaneous adjustment of the air and petrol supplies by means of a floating piston and taper pin, as in figs 26 and 27.

(5) By the use of duplex and triplex petrol nozzles in combination with a supplementary air supply, as in figs. 28 and 36.

(6) By variable pressure on the petrol feed to single-, double-, and multiple-jet nozzles, as in figs 29, 30, 31, and 38.

(7) By simultaneous throttle control of the air inlet to, and mixture outlet from, the carburettor as in figs. 14, 20, 32, 33, and 34.

(8) By progressively controlled petrol nozzles, as in figs. 35 and 36

(9) By mixed methods, as in figs 27, 28, 37, and 39.

Considering the different methods *seriatim*, it is seen that a greater number belong to category (1) than any other, this including all carburettors in which the necessary supplementary air for a non-automatically controlled petrol supply is admitted by either a spring-loaded lift or piston valve, for forming automatically a mixture suitable for a variable speed motor. Under this category many of the carburettors are really an adaptation of the original Maybach, and were the most commonly used for automobile and other petrol motors, required to run under variable power and speed control. In carburettors of this type, in which the jet volume is controlled simply by a variable depression in the mixing chamber, as by induction caused by a constricted tube, what is wanted to correct the difference in the flow of the air and liquid is a comparatively large valve having a very sensitive action, so as to quickly respond to slight differences of pressure in the

mixing chamber, caused by variable throttle opening and piston speed. Fig. 21 represents the Kreb, in which a piston controlled by a large diameter diaphragm plunger, M, is adapted for this purpose. In this carburettor the pressure plunger works

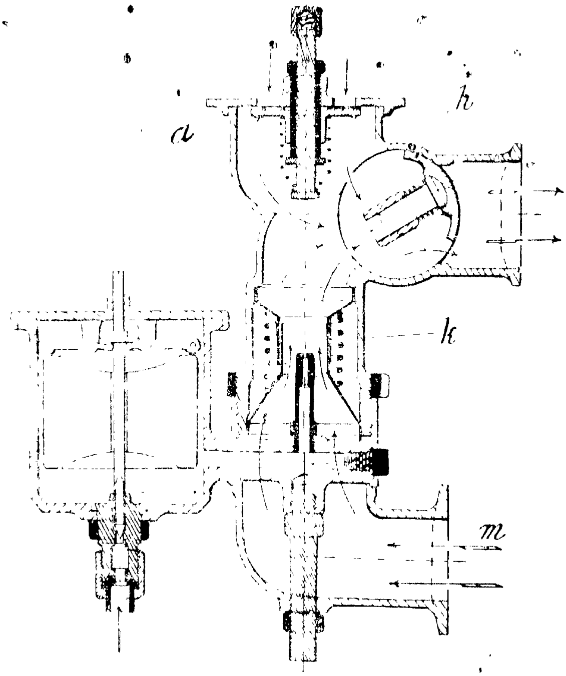


FIG. 22.—Single jet automatic carburettor with spring-controlled supplementary air disc and Corliss throttle—Brown-Barlow.

in a casing open at its under side to the mixing chamber and closed at the top, excepting for a small aperture that can be adjusted to damp out unnecessary oscillation. The objection to this is the lack of free movement in a dusty atmosphere when constructed to work with a sliding action, and its short life when arranged as a flexible diaphragm. For motors not required

to run over a very wide range of speeds, a properly proportioned combination of the five essential components of this form of carburettor—viz., the float-feed cistern, petrol nozzle, choke tube, air valve, and throttle, can be made to work surprisingly well. In the example (fig. 22), one feature is the easily replaceable choke tube, *k*, for one of the exact diameter best suited for the motor; another, the light air valve of large diameter, *a*, with sleeve guide. The spring-closed Corliss throttle, *h*, is also a good feature, as this ensures an air-tight fit after considerable wear, plus a nicely graded adjustment for slow running when formed with a vee or slanting closing edge.

In regard to size, for moderate speeds—*i.e.* not exceeding 1000 revs. per minute—the primary air inlet, *m*, should be not less than one-third the diameter of the motor piston and the mixture outlet one-half. The diameter of the con-divergent air nozzle, *k*, at the throat may vary from one-fifth to one-sixth, according to the speed the motor is required to run at; obviously, this simple non-contractile form of air nozzle is not adapted for very low speeds.

In order to obtain a more delicately controlled degree of carburetion adapted for a wider range of speed—*i.e.*, to be able to supply a suitable mixture alike for speeds accelerated above normal, and for regular running when slowed down declutched, which is very difficult to obtain with a carburettor of the ordinary spring-controlled supplementary air-valve type, a very scientifically designed carburettor, known as the Xenia, was originally used on the Crossley automobile. In this, illustrated in elevation and cross-sectional views (fig. 23), there are features of extreme interest. For instance, in place of a spring-loaded air valve, a piston *r*, connected to a float, *f*, and mercury syphon cistern is used. In this carburettor the varying degree of suction effect or vacuum, resulting from throttling of the mixture supply to the motor, causes the mercury to rise or fall in the central chamber, and the float, *f*, and air piston, *r*, to follow suit, the action being identical with that of an ordinary dial barometer. Petrol is supplied to the spray nozzle, *p*, from a float-feed cistern in the usual way, and is sprayed into the "venturi" nozzle, *x*, to which the supply of air is not regulated. The supply of mixture to the motor through *m* is controlled by the hollow

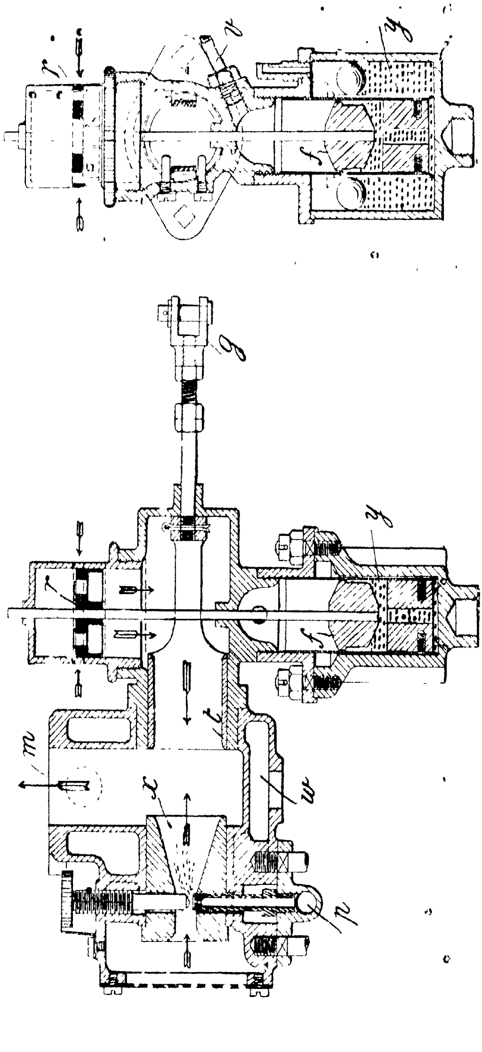


FIG. 23.—Automatic carburetter with single deflected jet across venturi tube, hollow piston throttle, with air admission controlled by float on mercury bath open to mixing chamber.—Xenia-Crossley.

piston valve, *t*, and governor connection, *g*; this valve is moved in a direction away from the spray nozzle to speed up the motor, when, in order that additional air may be supplied, the supplementary air-piston valve, *r* is allowed by the float, *f*, to fall, so opening the series of air inlets around the air-inlet piston. The reason that the float falls on "full-throttle" opening is due to the vacuum or suction effect in the mixing chamber being reduced, and as this part of the carburettor is connected by a pipe, *e*, to the float chamber of the mercury syphon, *y*, the vacuum here is also reduced, and the level of the mercury in the outside chamber, which is open to the atmosphere, proportionately rises, but on closing the throttle, *t*, the suction in the mixing chamber will be increased, when the mercury in the inner and outer chambers will assume their greatest difference of level The balls shown are for the purpose of preventing splashing of the fluid in jolting over rough roads, the communication from one chamber to the other is by a small opening in order that oscillation of the mercury column shall be prevented. The air supplied to the nozzle, *x*, is not under variable control, and in order to maintain carburetion constant when the supply of mixture to *m* is reduced as when the motor is slowed down—for instance, by moving the throttle, *t*, towards *x* (so choking the supply outlet)—the mercury column under *f* is drawn up by the increased vacuum in *m*, and the valve, *r*, raised, thus closing the supplementary air inlet. For this reason it is possible on quite slow speeds totally to cut off the air supply from *r*, and as the venturi nozzle, *x*, is of very small diameter, the air velocity and suction effect will continue to cause the jet to play at a very low speed of the motor The mixing chamber is warmed by circulating water from the motor through the jacket *w*.

Although much has been said on the subject of automatically controlled mixture supply, it is none the less a fact that in order to obtain the very best effect many expert drivers used to prefer a hand-controlled carburettor, and for the same reason these are invariably used on racing cars where speed, and speed alone, is considered. Other things equal, the most efficient carburettor is one that will mix petrol with the air on its passage to the motor cylinders with the same unerring certainty at one speed as at another, and produce this effect with the least possible

throttling action on the motor, and when the carburettor is so constructed as to be non-automatic in action; for this result to be obtained with the minimum trouble on the part of the motorist, needless to add, there should be no choking of petrol nozzles or sticking-up of air regulators.

The fault of too many carburettors is their difference of behaviour with different drivers, this being in part accounted for by (1) wide range of non-indexed adjustments, (2) the number of low grades of petrol now distributed, (3) a general incapacity for easy starting combined with the attainment of a high economy over a wide range of speed control, or (4) to requiring such skill in handling and adjustment that probably but few receive. These factors taken into consideration with the almost confusing variety labelled "automatic"—*i.e.*, carburettors that should be capable of permitting a motor to start with the first 'pull over," to run smoothly at 'stand-by" speeds, to instantly respond with good effect for whatever speed or power the motor may be capable of, and withal be absolutely reliable and independent of hand adjustment, at least presupposes a very perfected instrument, and, judging from the extreme diversity in design as evidenced by the following examples, can but point to the conclusion that finality has not yet been attained, even when allowing for the number and widely varying applications for which petrol motors are now in such demand.

The objection to spring-loaded supplementary air valves of whatever form is the progressively increasing tension or pression of the spring: for instance, if it requires a pull of 1 lb. to open a "lift valve" against the resistance of a helix of round or square wire, coiled in parallel form to raise it one-eighth of an inch off its seat, it will need double this pull to double the opening. By using a tapering ribbon coiled in a conical form, this progressive increase lessens to a degree according to the flatness of the cone and in a spiral or clock spring the resistance increases in greater ratio, owing to the decreasing diameter of the coil, but can be equalised by a fusee, cam, or variable leverage connection, and has been adopted in the Excelsior carburettor (fig. 24), where the air valve, *a* (quite a thin disc of large diameter) is connected to a spiral spring enclosed in the case, *g*. In this carburettor (usual in American practice)

the petrol nozzle, *z*, projects across the throat of the venturi tube, *v*, in this instance, in salamander form, so that drip at starting, as by flooding, shall be carried up. The advantage of projecting the jet crosswise is due to the facility with which this method lends itself to adjustment by a taper-pin regulator, as at *n*. A metallic ball is located in the divergent end of the tube,

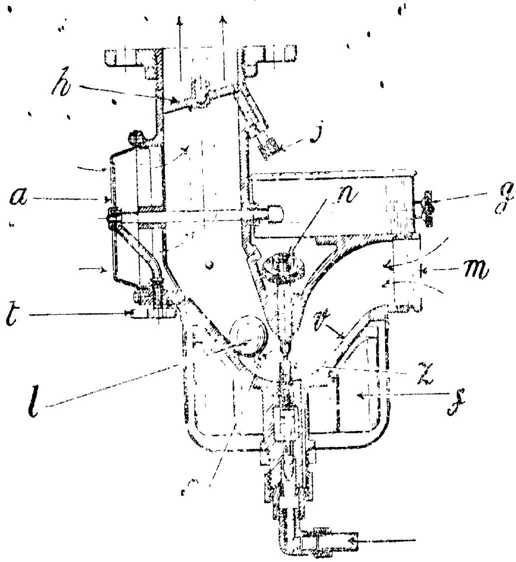


FIG. 24.—Automatic carburettor with pin-deflector single jet in waist of salamander venturi tube, and supplementary air by sensitive bell-spring controlled disc Excelsior.

resting loosely on a stop, *s*, this ball, with the motor in action, is held suspended between the two stops, and tends, of course, to obstruct the flow, which is what in most makes it is the endeavour to prevent, but is probably found to be a corrective to the jet at varying speeds. In starting, the valve, *a*, is held closed by the stop *t*, and for slow running the throttle, *h*, is closed against the stop-screw, *j*.

In the Shebler central float-feed automatic carburettor (a

well-known make), some of the objections to a spring-loaded supplementary air valve are minimised by fitting this with a long conical-shaped spring. This valve is of large diameter, and made of fibre with a brass backing disc and sleeve, it is therefore silent in action. Another is the Breeze (more suitable

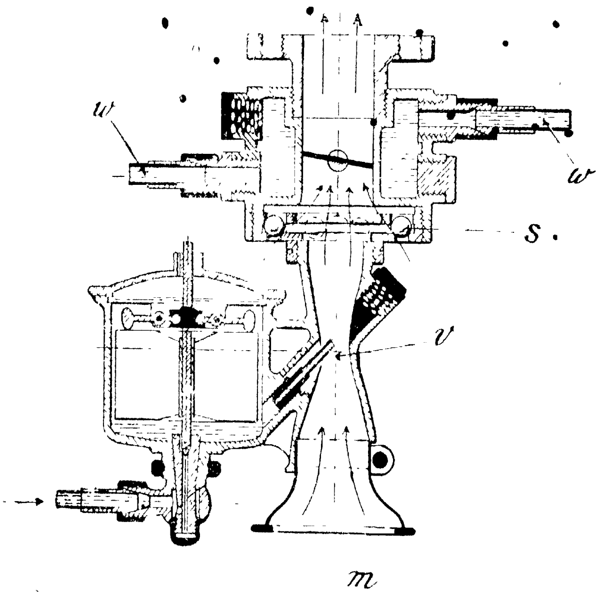


FIG. 25.—Venturi tube carburettor with oblique jet in waist and supplementary air controlled by series of ball valves of varying density—Grouvelle.

for cycle motors), in which there is also a conical spring-loaded fibre valve. Both of these have a taper-pin adjusted petrol nozzle and con-divergent induction tube. It will be seen that the modified forms of carburettors shown in figs. 26, 27, 28, and 37 depend on their automatic action from either a spring-loaded valve or sliding piston.

One advantage in the use of spring-closed valves is quick-closing action when subjected to a back flow; spring-loaded

valves have for this reason been adopted in the Sunderman "safety" carburettor to obviate any possibility of danger from a "back fire." In this, not only are both main and supplementary supplies fitted with spring-loaded valves, but the mixture supply as well, thus making doubly sure against the escape of a flame under any circumstances

(2) *Carburettors in which mixture formed by a non-automatically controlled jet is corrected by a supplementary supply through gravity loaded ball, plug, plunger or piston valves.*—In order to correct the tendency for spring-loaded valves to admit too much extra air at starting and while running light, also to obtain a more uniform action at different temperatures, and further, to prevent unskilful adjustments,—weight-loaded lift valves of the ordinary type have been tried These in practice, however, are found to lift irregularly, especially at low speeds. This tendency can, of course, be damped out by a plunger, but adds friction and worse, as a plunger is liable to stick fast from inattention The mercury float piston automatic control, shown in fig 23, is a very effective application of the gravity principle, as in this instance its movement is not only comparatively positive, but extends to a wide range An interesting application of the gravity system is shown in fig. 25, where a series of metallic balls, *s*, of differential weights, is used, these in starting and while running slow rest on their seats; but on further opening of the throttle and speeding up of the motor, lift off their seats progressively and without a chattering action, which is so objectionable a feature in disc valves. In this carburettor, known as the G.A, there is a long venturi choke tube, *v*, with the petrol nozzle arranged obliquely at the throat, no pin-feed adjustment is used, but the plug opposite lends itself conveniently for removal or cleaning of the nozzle, which is a good point.

Differential weight ball valves for supplementary air supply is the method also used in the Kingston central-feed carburettor In this instance the choke tube is vertical, short, and annular, and the spray from a pin-adjusted nozzle is induced, together with an atomising series of air jets, up a central tube, the disposition being somewhat similar to the carburettors shown in figs 10, 12, 12A, and 15, excepting that the main

air supply is drawn through the annulus and the atomised spray through a central divergent nozzle. The float cistern is arranged centrally around the venturi mixing uptake, and together with the air inlet can be clamped at any convenient angle, which is a good point.

The Bariquand carburettor is another example without a spring-controlled supplementary air supply. In this instance a ported piston carrying the choke tube is drawn up by suction effect against its own weight, thus registering to a greater or less extent with a series of air ports in the casing. This, in common with all carburettors having automatic sliding mixture regulators, is not so suitable for an automobile for use on dusty roads, although for marine and stationary motors working in a clear atmosphere, and therefore free from liability to get stuck fast, sliding regulators, owing to their steadier action, have an advantage over the ordinary lift valve.

(3) *Carburettors in which the quality of the mixture is regulated automatically by augmenting or diminishing the capacity of the air induction tube.*—This is the method adopted in the earliest adaptation of the jet principle, as shown in figs. 11, 12, 12A, and later, in fig. 15; this method has also been used extensively in petrol paraffin carburettors having an exhaust-heated vaporiser attachment (see Chapter V.). In carburettors of this type a con-divergent induction nozzle is used in which the divergent end projects into a globular mixing chamber in such manner as to leave an annular space surrounding the neck of the nozzle; into this a combined jet of air and petrol is induced past a hollow screw-down regulator having a fine thread, thus forming an annular jet of extreme attenuity. The necessary depression in the mixing chamber is regulated by a pulsator plug against the pull of a spring, thus automatically varying the air-way area at the throat of the nozzle. In this inspirator form of carburettor the maximum advantage is taken of the vena-contracta principle, inasmuch that the rich mixture of spray and air is drawn into an annulus and separated from the high-velocity air flow by a thin divergent neck; the stream is thus swept forward by the main air flow in a stream-line direction. As a result of this, the depression produced in the annulus on the jet is from 3 to 4 inches lower than that

in the mixing chamber. Thus in place of the liquid being induced into the air stream direct in the form of a solid jet, or obliquely as a diffused jet, or worse, as when fed into a high-velocity air stream crosswise against the current, the mixture is induced in the form of annular stream and in the same direction as the main air stream, the two streams thus combine with a minimum of fluid resistance. Indeed, in carburettors of this form, such is the suction on the fuel feed that it is not so very important to adjust the level of the fuel supply to within an inch or so of the apex of the fuel regulator, in fact, several inches of difference of level has little appreciable effect on the running of the engine, so long as the level is maintained constant, the pulsator lending itself by endwise and spring adjustment to a considerable range of suction effect. In emphasis of the depression that can be produced at the fuel nozzle in this inspirator form of carburettor first used by the author, hundreds of engines are still at work, in which the fuel (paraffin) is drawn direct from a tank constituting the base of the engine.

The inspirator method is equally adaptable as a mixer for gas engines, and has the advantage of making an engine practically independent of pressure, as the gas is drawn past a spring-loaded valve; this is shown in fig. 41, as an "adapter" suitable for any ordinary form of petrol carburettor to enable an automobile to run on gas.

But the greatest advantage of the inspirator, whether used as a simple carburettor for petrol or gas or for paraffin or semi-refined oils in combination with a vaporiser, is its adaptability for a bi-fuel feed, by simply fitting two inlets around the nozzle annulus, one connected either to a regulator-controlled gas supply or to a petrol cistern, and the other to a vaporiser and paraffin cistern. The inspirator mixer also lends itself for a third regulator, by which a paraffin engine can be fed with a water spray to suppress the detonating effect of this fuel in engines with exhaust-heated vaporisers when on full load.

It will be observed that in other forms of carburettors (shown in figs. 26, 27, and 37) a regulator plunger is used to automatically vary the area of what approximates to an air nozzle, also that in figs. 18 and 19 a plunger piston is seen to

vary the position of a venturi choke tube over a single-jet nozzle in one instance and a multiple-jet nozzle in another, these in each case acting by suction effect against gravity. Air-way automatic control on this principle is adopted also in the S.U., Scott-Robinson, Ideal, Smith, Stewart, Holtzer, and other carburettors, excepting that in some the petrol supply is synchronously varied either by a taper pin or by putting multiple nozzles into or out of action successively. In all of these the air supply is regulated by the action of a varying depression in the mixing chamber to draw up a piston plunger against its weight alone, no springs being necessary. This method, however, will not work satisfactorily when applied to a stem-guided pulsator plug as, for example, in that shown in fig. 15 unless fitted with some means, as by a spring, to damp out excessive oscillation.

(3) *Carburettors in which the petrol and air supplies are simultaneously regulated by a floating piston or plunger.*—In these there is no induction action on the petrol supply, the jet issuing by depression only, and being regulated by either varying the area of a single jet aperture, or by bringing into action, or closing, a succession of jets by the rise or fall of a piston plunger in consonance with the position of the mixture throttle. The air supply is automatically regulated in proportion to the petrol, simultaneously and more definitely, perhaps, than by a varying inductive effect, in combination with a depression-actuated air supply, depending on correct adjustment of spring resistance. There are two methods for regulating the air supply, one by varying the area of a divergent nozzle, as shown in fig. 26, the other by arranging the piston plunger to open or close a series of ports in the cylindrical guide to a varying extent, as shown in fig. 27, the action and effect for both being very similar.

The advantage of this form of carburettor is that, after once being correctly proportioned, they give more perfect and reliable carburetion than carburettors with independent petrol or air adjustments, or both, in the hands of users not sufficiently adept to get the best out of them; but, *per contra*, they require to be very carefully made, and are not so suitable for a motor working in a dusty atmosphere, unless provided with an effective strainer.

Apropos of this, it may be said that a dust arrester is really just as necessary for the motor, although not so obvious; the effect of dust is nevertheless very destructive to both piston and cylinder, and can readily be realised on cleaning out an air filter after a few hours' run over dusty roads. Touching on this point,

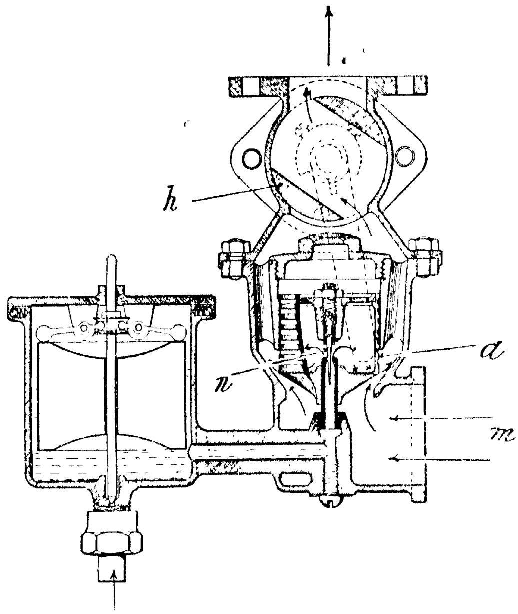


FIG. 26.—Automatic variable jet carburettor with gravity-suction controlled air and fuel admission—Scott-Robinson.

there is a certain objection to any apparatus that materially interferes with the free inflow of air to the carburettor, such as by the use of layers of fabric laid over gauze; unless of ample area and frequently cleaned. One of the most practical means for arresting dust is an aluminium rectangular box having a number of thin gauze-backed baffle plates, arranged in such manner that the air is circulated to and from the divisional

spaces between the gauze-covered plates passing around at opposite ends. A layer of oil which may be such as drawn from the crank-case is poured into the filter, and this by capillary attraction and splash keeps the gauze wet and so catches hold of the dust. Other means will suggest themselves, but nothing is of any practical use that is liable to choke the free passage of the air-flow.

Reverting to floating piston-plunger carburettors, a good example is shown in fig. 26, this having a taper-pin controlled petrol feed, and is a method more commonly used than any other. In this the plunger *a*, with throttle *h*, in position for starting or running, will float just off the coned mouth of the air intake, *a*, when an extremely attenuated stream of petrol will be drawn from the nozzle, *n*, to the series of holes around the bottom edge of the plunger, whence it combines with the air, the two fluids being increased proportionately as the plunger rises with further opening of the throttle. The plunger is grooved to minimise friction, and is of sufficient weight to balance suction effect, and the guide is closed at the top, thus serving to steady the movement of the plunger.

Another variant of this type is the S U., but differs in the disposition of the parts. In this the air-plunger regulator, with petrol-feed taper pin attached, is arranged at an angle of 45°, but more for harmony in general design than for any other reason, the principal difference consisting in the use of a concertina form of bellows of about twice the diameter of the plunger piston, the interior of the bellows is placed in communication with the mixing chamber, thus, owing to its much larger area, flexibility and non-contact with the sides of the containing case, the movement of the air plunger is more sensitive to slight depression changes in the mixing chamber.

The Newcomb carburettor shown in fig. 27 is another of this type, with taper-pin controlled petrol feed, as at *n*; this pin, moving with the plunger *a*, is graduated for a feed in proportion to the port openings, for the admission of air to the mixing chamber surrounding the plunger guide. An important feature in this carburettor is the corrective means adopted as at *r* to vary the petrol feed by placing the float cistern into communication with the mixing chamber; thus with an increased

depression following a wider opening of the throttle, *h*, there is a correspondingly diminished pressure acting on the petrol, the feed is therefore reduced. To emphasise this effect, the communicating pipe, *r*, ends in a form of Petot tube, the depression can be adjusted by admitting more or less air by the cap, *p*,

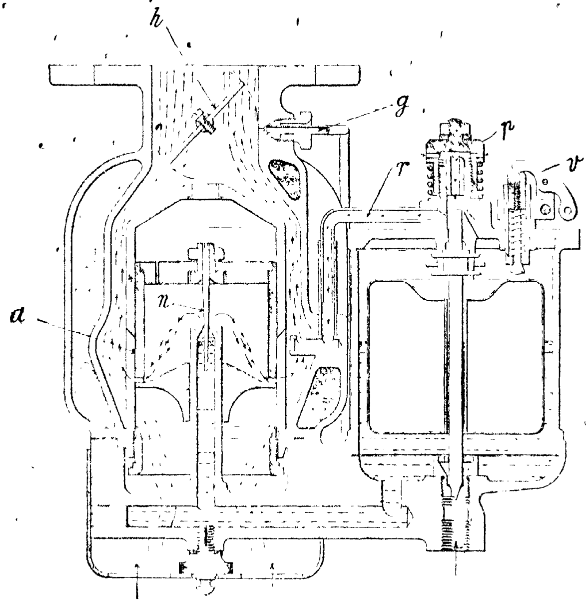


FIG. 27.—Variable automatic carburettor with gravity suction air and fuel control plunger and nozzle pin, plus variable cistern pressure. Also fitted with auxiliary jet for starting and running slow. Newcomb.

and can be neutralised altogether by opening the valve, *v*, by a cord within reach of the driver. There is also in this carburettor an auxiliary jet, *g*, located so that on the throttle, *h*, being closed, excepting for a slot cut just opposite the nozzle inlet, a great suction effect, as at starting, will be centred at this point, while cranking over the motor. On further opening of the throttle this extra depression ceases, and the auxiliary jet is then put out of action.

The Stewart, or S.P.C., is another carburettor of the floating air-valve synchronously controlled petrol-supply type. In this there is a central feed, thus making for compactness in design; but the principal difference is in the jet regulation, as in place of a taper pin attached to the air-plunger regulator, the pin forms part of a set-screw protruding at the base of the cistern' the jet can thus be adjusted, which is an advantage if understood Over this pin, which is below the level of the petrol, there is a tube forming part of the air plunger, and thus the jet and air supply are automatically regulated together and in accordance with the opening of the throttle.

The Ideal carburettor (Colin Scott) is very similar to this excepting that in place of an adjustable taper pin at the base there is a double-jet nozzle capable of an extremely fine adjustment by means of a clearly marked micrometer gauge, thus the reading for any given result can be noted, and the running of the motor tuned up with less trial and error than with non-indexed adjustments. In this the jets are automatically regulated in volume by a tube attached to the air plunger; the tube has a pair of narrow slots, and on being drawn up over the nozzle by the plunger, increases the feed in direct proportion to the air supply and throttle opening.

A similar result is obtained in Smith's variable feed-floating piston carburettor by progressively bringing into action a multiple series of fixed solid jet nozzles, in this case four, by the movement upwards of a hollow piston or cap over a series of four ports at different heights, communicating with a four-chambered mixing tube, at the base of which the four nozzles project, and are brought into action in successive order according to the number of ports uncovered by the piston. The jets are of slightly diminishing capacity, the first being the largest, and the port controlling the mixture formed by this is the one used at starting and for slow running, and is never more than half closed. On this port being three-quarters opened, the next commences to be uncovered, and so on until each of the four ports are open to the depression chamber surrounding the ported four-chambered fixed piston and rotary throttle. As in all solid jet springless carburettors, tuning to the particular motor and running conditions required is effected by changing

the petrol nozzles, which can be done without dismantling any part, other than the float cistern.

The piston-plunger automatic air-regulator type of carburettor also lends itself for a bi-fuel feed, which may be petrol and a mixture of petrol and paraffin, benzole, alcohol, or even paraffin, when suitably arranged for heating the mixture This is done in the Hamilton bi-jet carburettor, in which a depression-regulated piston plunger (usually equal to about 4 in to 5 in, as in general practice) carries two taper pins for a pair of fuel nozzles, each supplied by a separate float cistern. In action the jet from the petrol nozzle is adjusted with a slight lead, so that for starting and running slow only petrol is used, but on a further lift of the air-piston regulator following a greater opening of the throttle, the paraffin jet is brought into action, thus at half throttle, while the two fuels are used in about the same proportion, the petrol supply at full throttle falls to about one-third of the total fuel consumed, but can be varied by the setting and taper of the nozzle pins for different fuels, according to requirements.

(5) *Carburettors in which duplex and triplex petrol nozzles are used, each having a separate induction tube, in combination with a hand- or automatically-controlled supplementary air supply.*—In view of the extreme range of speed now considered necessary for road-car motors, especially those of the touring type, it is no wonder that multiple nozzles have been employed to come into action progressively as the speed increases. One advantage gained is the suppression of the starting and slow-running auxiliary jet, as used in many carburettors having only a single-induction tube of fixed area In this category only those carburettors are described in which duplex and triplex induction tubes are used in combination with either an automatic or hand-controlled supplementary air supply.

Of these the Diezman (Stevens Manufacturing Company) is one having the maximum range for adjustment, and commends itself to users having the necessary skill and patience to make the best setting of the three variables—viz., jet, air, and throttle; and as in this, shown in fig. 28, there are two separate mixing tubes, k^1, k^2, each with its own throttle, h^1, h^2, interconnected, there is therefore opportunity for some confusion, but when properly

understood can be set to respond to the most exacting demands. The *modus operandi* in starting is to have throttle h^1 held closed by its spring, and throttle h^2 slightly open, as for running slow (the opening for this being determined by the set screw, t, in the usual way). The jet from nozzle z in the con divergent induction tube, k^2, can then be adjusted by the set-pin, n, to give the feed required for steady running "slow" and for speeding up, with

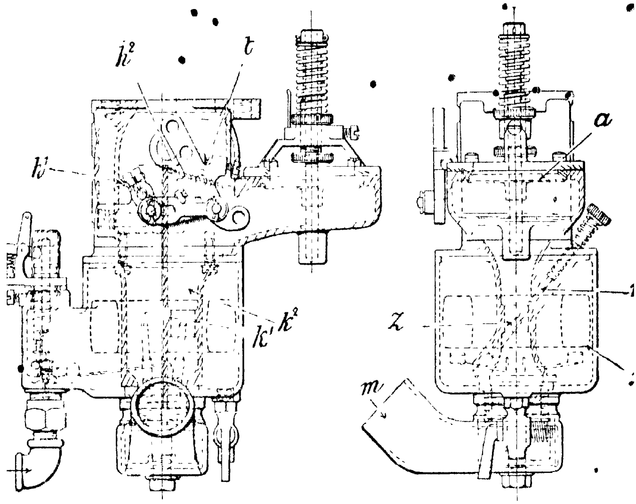


FIG. 28. Double throttle twin-deflector jet carburettor with spring-controlled supplementary air and central float feed cistern (Diezman).

throttle h^2 half open, at which point the second throttle, h^1, commences to open, the lost motion in the connecting link permitting of this. On the depression below the throttles exceeding 3 to 4 in. or thereabouts, the valve a commences to admit supplementary air, the need for this being more obvious as the speed goes up. This valve has been very carefully designed for capacity, adjustment, and quiet action, also the means for setting the spring pression and for locking in correct position is both facile and certain. There is another point that should not be overlooked, and that is the steadying effect on the valve of

the socket guide at the bottom of the stem. The float feed too is a great improvement on the common practice, for not only is the ring float poised to maintain a level position, but, what is more important and early discovered by the writer, the feed valve is held down to its seat by a spring, thus obviating "overflow," a fault only too common in many carburettors unless turned off at the main soon after stopping the motor.

The Binks is another double jet carburettor with independent throttles, in this instance spring-loaded lift valves, the smaller of which, in capacity about one-sixth, having a considerable lead over the larger throttle. This method of controlling the mixture supply lends itself for using fuels of different densities, and has been adapted as such. A feature about this carburettor is the absence of adjustments, the method for tuning to any particular motor or running condition being replacement of the induction tubes or petrol nozzles, or both; this is, however, quite a simple matter, as the tubes are quite short, very accessible, and only require a single wing-nut to clamp both in position. Supplementary air is arranged for by a hand-operated disc valve. This in an earlier design was interconnected so as to be under single control, but there are so many different brands of petrol and of such varying density and flash-point now, that many owner drivers prefer a dual control. The strong point about this carburettor is its absolute immunity against sticking up; the mixture throttles, again, are a ground-in fit, and the float feed even is of the hinged, spring-closed, positive type.

The Bailey bi-jet carburettor is somewhat similar, the two detachable choke tubes and nozzles being in proportion as 1 to 6; but in this make there is a double-ported mixture plug throttle, arranged for the small tube to be brought into action in advance of the larger tube, while an ordinary direct-action float cistern is used, the supplementary air supply is by a separate, hand-operated ported disc, and, as in the previous example, any necessary jet adjustment is by change of tube and nozzle.

In the Trier and Martin three-jet carburettor there is both a hand- and automatically-controlled air supply. This (known as the T. and M., see fig 29) has three nozzles, c, brought into action progressively by an extension to the hollow throttle piston, on this being moved to the right, thus simultaneously uncovering the

supplementary air port, *a*, and mixture throttle openings, *h*; air also enters through openings *m*, which can be adjusted in area by the shutter disc shown; the only automatic supply enters by the air-way afforded by the extension inwards of a closely coiled, fine helix attached to the movable disc; this spring carries a cap, and is thus closed at its inner end, but on the depression over the nozzles exceeding 4 or 5 in., as when the throttle is fully open, the spring is drawn forward, thus widening the interstices between the coils. The slightly vee-shaped ports, *a*, are entirely

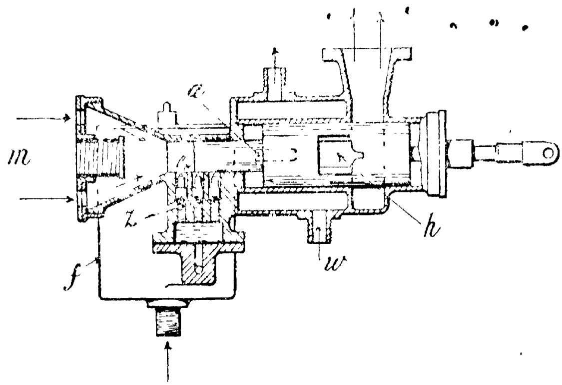


FIG. 29.—Triple jet carburettor with hollow differential piston air and mixture throttle control—Trier and Martin.

closed while running slow and at starting, with only one jet in action, as shown, when the only throttle opening is through the narrow extension slotways shown in *h*, and that for the air supplied through the ports, *m*, the disc shutter is then "set" to obtain smooth running at this stage. There is really a fourth supply, as there is a small lateral aperture leading from the outside to the space surrounding each of the three petrol nozzles, but is more for atomising the jets than for supplementing the air supply.

(6) *Single-, double-, and multiple-jet carburettors in which pressure on the petrol feed varies as the opening of the mixture throttle.*—Under this category are included carburettors relying

entirely upon a variable jet velocity derived from a variable pressure in the float cistern, this in general practice being constant and open to the atmosphere. also two- and three-jet carburettors, in which the jet velocity and number of jets in action is determined by variable level in an auxiliary well. There are also modified forms of carburettors in which the jet velocity is only in part influenced by a variable pressure in the float cistern, and mainly by a variable induction effect, as shown in figs. 27 and 38

The Gillet-Lehman, known as the G L, is an example of those depending entirely on a variable pressure in the float cistern, in this class only one central jet petrol nozzle is necessary, without any supplementary air supply, either hand or automatically controlled. the air-way area may or may not be increased in proportion to the throttle opening, as shown in fig. 30. In this instance a drum throttle is used having a cam-shaped core, *h*, which on being rotated clockwise leaves an increasing opening under the mixture outlet, and simultaneously widens the air-way opening, *l*, on two sides of the nozzle nipple, *z*, so that in this respect this carburettor in part belongs to category (7) However, its action does not depend on the vee-shaped slot opening, *t*, cut in the periphery of the drum throttle, and will work with a parallel opening, the purpose of the narrowing width being simply to cause the air to flow past the jet with a constant velocity Its *modus operandi* is to cause the pressure in the cistern either to supply the nozzle with petrol at the maximum level of the jet orifice, or to reduce this level to the bottom of the nozzle, according as the duct, *c*, is placed into communication with *a* or *d* by means of the groove, *e*, as with the throttle closed or full open. Any intermediate effect, as obtained from placing the cistern open to the outer atmosphere, or to the vacuum above the throttle, can be produced by the regulator plug, *g*, so that it will be seen a great range of depression is possible.

In the Holley carburettor (fig. 31), adopted by the Ford Company, the possible difference in the petrol level at the nozzle is very slight, but is compensated for in part by air admixture. The cistern, as will be seen, is of the concentric type, with a cork float, *f*, petrol flows past a nipple, *n*, of a determined gauge to

an inner well surrounding the nozzle casing, and thence through a series of holes below the regulator pin valve, p, to the jet. In running slow, and of course while the motor is not in action, the

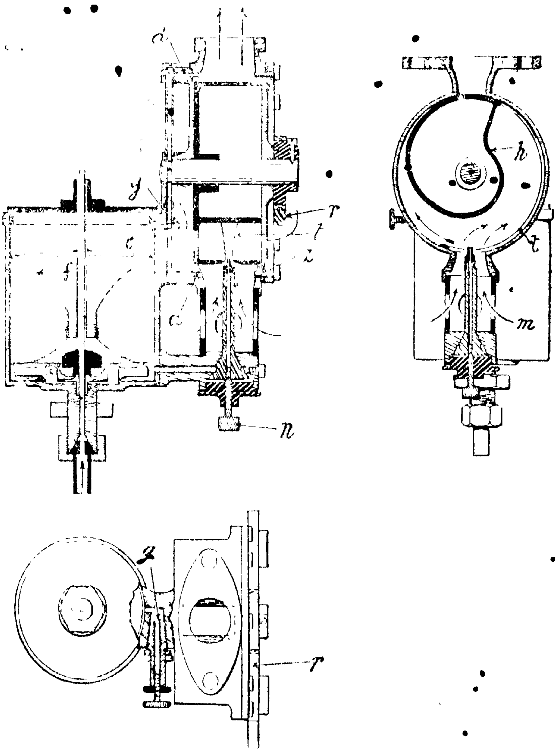


FIG. 30.—Variable pressure angle-jet carburettor with synchronous action air, fuel, and mixture control—Gillet-Lehman.

level in the cup above the nozzle will rise to that in the cistern and be above the bottom of the tube, t, supplying the auxiliary nozzle, s; thus with the wing throttle, h, as shown, there is a considerable suction on this nozzle, sufficient in fact to draw up

petrol and cause it to issue in the form of a jet in the recessed end of the starting nozzle, the space thus left open on the edge of the throttle wing, *h*, is the only passage for air during the

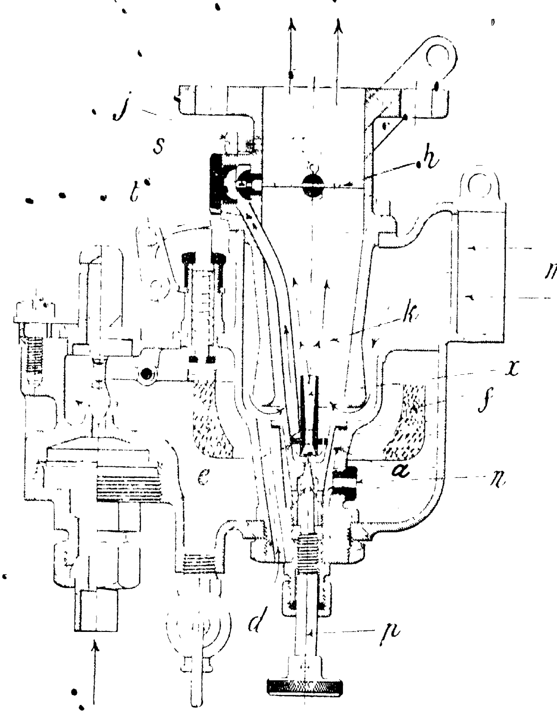


FIG. 31.—Variable action single-jet central feed carburettor with throttle-controlled auxiliary jet for starting and running slow—Holley.

process of cranking over. The orifice in the divisional ring, *e*, should be of just the size to feed the jet at *s* while running slowly, for if in excess of this, it not only leads to waste but tends to a smoky exhaust and fouling of the igniter insulator. On further opening of the throttle and speeding up of the motor the level of petrol in the cup above the divisional disc, *e*,

rapidly decreases until, at high speeds, it is drawn entirely from the jet. Soon the level gets below the atomising nozzle, *x*, and then air is free to pass downwards through the small orifice in the disc, *e*, and thus to mingle with the jet issuing from the nozzle controlled by the pointed regulator screw, *p*, and in this manner prevents too strong a mixture at high speeds. On slowing down the level again rises above the bottom edge of the tube *x*, thus strengthening the mixture, and on still further reducing the speed, the level will continue to rise and further enrich the mixture by reason of the lapping action of the annular downward current of air from *m*, in flowing up the main mixing nozzle, *k* to the outlet, past the full open throttle, *h*. In a later design of this carburettor the atomiser nozzle, *x*, and divisional disc, *e*, are dispensed with, and their functions performed by the nipple, *n*, and a breather tube extending from the top of the annular reservoir *a*, to above the level of the petrol in the cistern, in the cover of which there is also a vent hole. The mixture is thus regulated in strength by the rise and fall in level of the petrol supplied through the restricted aperture in the nipple, *n*, but as this by itself is not sufficient to prevent an excess of spray being drawn past the petrol nozzle at high speed, air is admitted down the breather tube (not shown) as soon as the level in *a* is reduced to a certain limit, and is then drawn up past the spray nozzle together with the petrol feed, and in this manner compensates for the increasing suction at the base of the mixing tube, *k*, at high speeds.

The Ware carburettor is designed on somewhat similar lines, but obtains the effect due to difference in jet velocity and petrol level in a simplified manner. In this (fig 32) petrol enters the float cistern past the weighted pin valve, *w*; hence the petrol flows through the restricted jet orifice in the nipple, *e*, into the well, *l*, and, when the engine is not running, rises to the same level as in the cistern, thereby submerging the end of the nozzle, *z*. Now, on starting by pulling over the handle with the throttle, *h*, closed a depression is caused above the throttle; accordingly, petrol is drawn up past the nozzle, *z*, and, mixing with a limited volume of air, is carried forward to the cylinders. Then, after a few minutes running slow, the jet, *z*, will be automatically put out of action, owing to the feed through *z*, due to

suction above the pipe, s, being greater than the feed to the well, l, through e, air is then drawn down the tube, b, and up, together with petrol from the surface of the contents in l, past nozzle, z, and up through the tube, s, in sufficient volume to keep the engine turning slowly. If the throttle is opened a little a depression will be caused above the surface of the petrol in l, and as this increases the flow through the nozzle, e, more will be drawn up the tube, b, to mix with air from m, if, then, the throttle is opened wide, the spray from the jet issuing from e will continue to ascend the tube, b, and to mix with a greater volume of air flowing past the restricted base of the throttle inlet. To compensate for the tendency for too great a feed when running with the throttle full open the increased depression above the tube, b, in lowering the contents in the well below the series of holes at the bottom, causes air to enter at a, and thus in reducing the depression above e regulates the velocity of the jet in proportion to the volume of air admitted through the throttle. As with all carburettors having jet orifices of fixed capacity, the only feasible way of adapting this carburettor to any particular size of motor, or running condition, is to fit a nozzle as at e, having a jet orifice of the exact capacity, as ascertained by running the motor under the required conditions. For slow running, however, a considerable range in

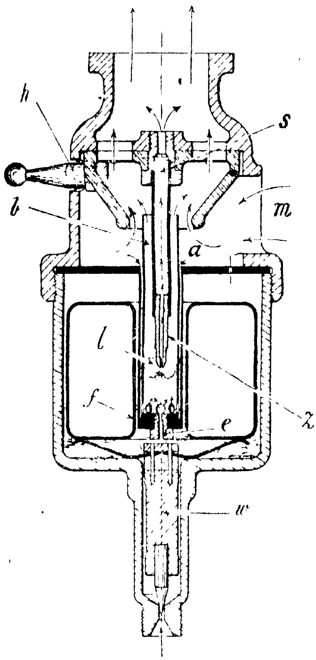


FIG. 32.—Central-feed automatically controlled double-jet carburettor: Ware.

effect can be obtained by adjusting the immersion of the starting nozzle, z, or again, by correcting the petrol level in the cistern.

One of the most extensively used, and coming under this category is the Zenith carburettor, shown in fig 33, this differing from the foregoing in having two running jets as

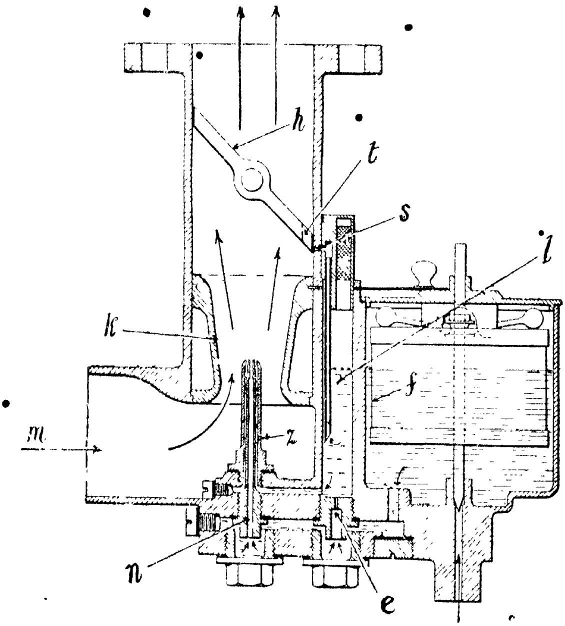


FIG. 33.—Double-jet differential-feed carburettor with throttle-controlled jet for starting and slow running—Zenith

well as an auxiliary jet for starting and running slow. This carburettor, in common with the foregoing examples illustrating the application of the pressure principle to obtaining a variable jet effect, is independent of any means for regulating the air supply; in this also, besides having an induction or choke tube of fixed dimensions, as in figs. 31 and 32, there is no means provided, nor needed, for regulating the petrol supply.

To obtain this result two spray nozzles are used, arranged concentrically; of these, the centre nozzle, *n*, delivers the main jet, and the annular nozzle, *z*, the compensating jet, the first is fed from a constant level—*i.e.* direct from the float cistern—and the other from a well, *l*, supplied at a fixed and predetermined rate by a restricted regulator nozzle, *e*. The form and capacity of the divergent mixing tube, *k*, is such as to oppose a minimum resistance to the air-flow while combining with this the highest velocity, the induction effect thus produced, due to restriction and velocity, being just sufficient to feed the necessary spray while running with the throttle, *h*, full open, when the level in the well, *l* will be at its lowest, the exact level being determined by the differential capacities of the annular orifice of *z* and the plain orifice in the choke nipple, *e*. Now, on running with the throttle, *h*, say, half closed, in ordinary circumstances, either the induction nozzle, *k*, would have to be more restricted, or a supplementary air valve provided between this nozzle and the throttle, partly closed, or again, either the pressure in the float cistern be increased, as in fig. 30, or the jet orifice increased, as shown in figs 26 and 27, or this effect obtained by the use of a progressively opened multiple series of jet nozzles. In this carburettor a constant mixture, or what is the nearest approach to it in practice (as really the mixture requires to be slightly richer as the volume supplied to the motor is reduced), is obtained by a variable level of the petrol supply to the compensating or secondary spray nozzle, *z*, for instance, with the throttle half closed the level of the petrol in the well *l*, will rise from 1 to 2 inches, which is approximately from one-fourth to one-half the total depression below the throttle, and thus is seen to have a material effect on the proportionate supply of petrol to the volume of air flowing past the two nozzles, *n*, *z*. Now, on further closing the throttle the level in *l*, by reason of the reduced inductive effect of the air-flow plus suction on the petrol nozzles, will rise still higher, and the proportional duty of the outer jet be greater, thus compensating for the reduced depression below the throttle. Again, with the throttle quite closed, as shown, excepting for a slot, *t*, cut opposite the jet orifice, *s*, there will be so little depression below the throttle as to be insufficient to overcome the surface tension of the liquid

in the jet orifices, for the reason that the velocity of the air past the primary and secondary nozzles will be so low as to have no material effect on the petrol contained therein, although less than one-fifth of an inch from the top. In this position, however, the suction and air velocity acting on the auxiliary orifice, *s*, is sufficient to cause petrol to flow up the immersed tube and be projected across the air-flow as a fine jet, even with the motor just turning slowly, and, what is more important, while pulling over the starting handle.

(7) *Carburettors in which a variable suction effect is produced by simultaneous control of the air and mixture supplies.* —Of all the different methods used to supply a mixture of constant strength, or what is sufficiently near to this for smooth and economical running of a motor over a wide range of speed and power, simultaneous control of the air and mixture supplies is by far the simplest and least subject to derangement under variable conditions, as with this method the jet orifice and pressure on the petrol feed can be constant, whether the air and mixture supplies are controlled by a single compound throttle, as shown in figs. 14, 29, 34, and 35, or by separate throttles interconnected. A carburettor of this type (Claudel-Hobson) is shown in fig. 34, in which the petrol nozzle projects right into the plug throttle, *h*, the air portway in this being so formed that when turned to the position S a narrow slotway extension, *s*, enables the air supply to be nearly shut off, and, simultaneously with this, for the mixture outlet, *e*, to be reduced, as shown in dotted lines, these two openings being so proportioned, one with the other, that suction on the petrol nozzle is then just sufficient for the air supplied (the exact opening of the regulator being determined by the set screw, *j*) for easy starting and in the required volume for the engine to run smoothly at a low speed unloaded; the position of the main passage in the plug is then horizontal. What may be considered a subsidiary feature is the use of an atomising cap, *c*, having perforations in line with the jet and around the base, thus causing the spray to issue across the current.

In the White and Poppe carburettor of this type, with double-ported drum throttle, the supply of petrol is graduated mechanically as well as by difference in suction effect. In this

make the orifice at the end of the petrol nozzle, which, as in the previous instance, projects into the hollow throttle, is eccentric to the centre of the throttle chamber, fitting over this fixed nozzle is a cap forming part of the throttle drum, in the top of this cap is a spray orifice, which exactly coincides with the jet orifice in the top of the petrol nozzle when the drum throttle is in full open position but which, on closing the throttle, is

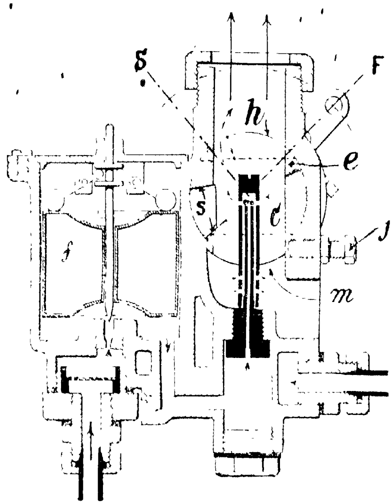


FIG. 34 Single-jet carburettor with plug throttle-controlled air and mixture supplies; shown with special atomising cap for starting and running slow—Claudel-Hobson

more and more covered, until, when moved into position for starting and slow running, the jet is reduced in capacity to that just sufficient to form a strong mixture with the then very reduced volume of air supplied. As in fig. 34, the air and mixture supplies are regulated together and in a practically direct ratio, but differ in this instance in simultaneously regulating the petrol feed. Obviously, the method adopted for this lends itself for precise adjustment by slightly changing the relative positions of the ported liner and nozzle cap with the fixed nozzle.

In the Miller carburettor a similar result is obtained by a combination of a mixture wing throttle with a hollow piston for the air supply, and taper-pointed regulator for the petrol nozzle, all interconnected, the mechanism being arranged so that both the air and petrol supplies can be conveniently adjusted relatively to each other and collectively to the mixture throttle; this carburettor, therefore, with its venturi air nozzle, concentric float cistern, and shutter control for the air supply, although included as a modified form under this category, materially departs from the unique simplicity of the plug-throttle type, as shown in fig. 34, with non-adjustable air and petrol supplies. Owing to there being no gravity nor spring-loaded regulator valves, carburettors coming under this category are peculiarly adapted for aero motors subjected to extreme inclinations and changes of temperature.

The Gallacher-Tompkins is another single-control carburettor without gravity or spring-loaded supplementary air control; this, however differs from the foregoing in having a combined mixture and air supply hollow piston throttle. There are also two petrol nozzles leading into a divergent mixing chamber, one with a screw-pin, hand-adjusted jet, and the other gradually brought into action by the piston throttle after starting. In this as in all throttles—wing, plug, or piston—the ratio of opening to air-way lessens considerably with the opening, and to equalise this the closing edge in a plug is inclined; and if a wing or lift-valve throttle, this should be opened with a progressively increasing movement; and in the case of a piston throttle this must be arranged to uncover delta-shaped openings, and, in this instance, such are provided for both the air and mixture supplies.

The Krice carburettor, shown in fig. 35, differs from either of those described, in that a rotable combined air intake and choke tube, *k*, fulfilling the functions of a throttle for the mixture and air supplies, is used in combination with an annular petrol nozzle, *z*, regulated by a screw-down valve, *n*. The action and form of this will be seen to somewhat resemble that shown in fig. 31, in so much as at starting, and while running quite slow, petrol will rise above the annular nozzle until it covers the lower end of the tube, *s*, when, with the rotable choke tube

and air intake nearly closed, and the outlet of *s* pointing to the opening, a supply of petrol, determined by the orifice at the upper end, will be drawn up direct, but, as described in connection with fig. 31, will cease with further movement of the throttle lever, *h*, when, with an increased velocity of the air down around the base of the mixture nozzle, petrol will next

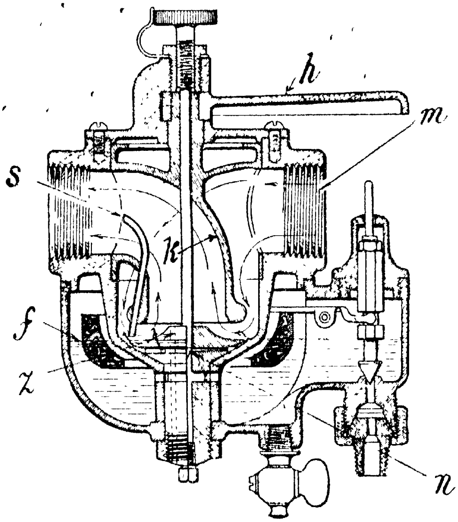


FIG. 35.—Central feed carburettor with annular fuel-jet and plug throttle controlled air and mixture supplies; also fitted with an auxiliary starting jet. Krice.

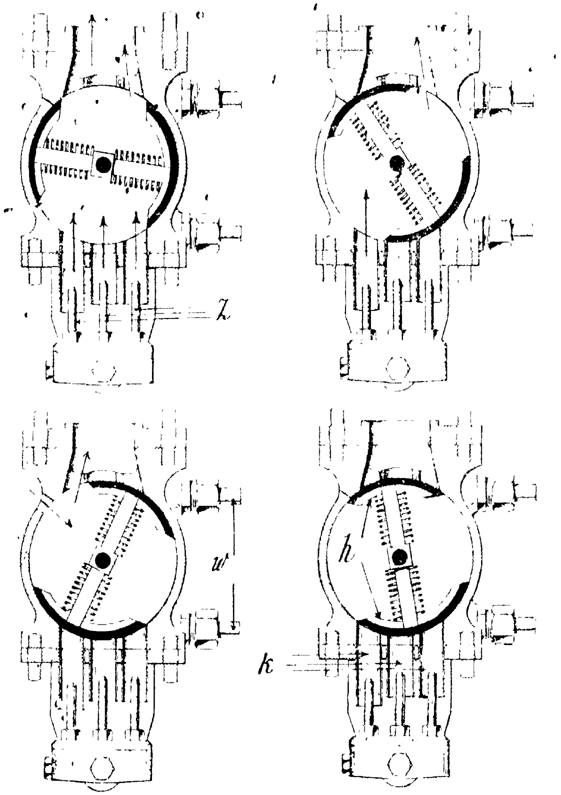
be lapped up from above the annular nozzle, further carburetion being regulated by increasing suction on the supply past the adjustable stop valve, *n*. The peculiarity of this carburettor over the Holley is that after once adjusting the feed with engine running at full throttle a proportionate feed is automatically obtained at all lower speeds. This effect is in part attained by the large diameter annular nozzle with splayed form of jet being opposed by the downward rush of air around the beaded base of the curved outlet, *k*, thus instead of a high velocity of air-flow having an inductive effect on the jet, as in

In the Miller carburettor a similar result is obtained by a combination of a mixture wing throttle with a hollow piston for the air supply, and taper-pointed regulator for the petrol nozzle, all interconnected, the mechanism being arranged so that both the air and petrol supplies can be conveniently adjusted relatively to each other and collectively to the mixture throttle; this carburettor, therefore, with its venturi air nozzle, concentric float cistern, and shutter control for the air supply, although included as a modified form under this category, materially departs from the unique simplicity of the plug-throttle type, as shown in fig. 34, with non-adjustable air and petrol supplies. Owing to there being no gravity nor spring-loaded regulator valves, carburettors coming under this category are peculiarly adapted for aero motors subjected to extreme inclinations and changes of temperature.

The Gallacher-Tompkins is another single-control carburettor without gravity or spring-loaded supplementary air control; this, however differs from the foregoing in having a combined mixture and air supply hollow piston throttle There are also two petrol nozzles leading into a divergent mixing chamber, one with a screw-pin, hand-adjusted jet, and the other gradually brought into action by the piston throttle after starting. In this as in all throttles—wing, plug, or piston—the ratio of opening to air-way lessens considerably with the opening, and to equalise this the closing edge in a plug is inclined; and if a wing or lift-valve throttle, this should be opened with a progressively increasing movement; and in the case of a piston throttle this must be arranged to uncover delta-shaped openings, and, in this instance, such are provided for both the air and mixture supplies.

The Krice carburettor, shown in fig. 35, differs from either of those described, in that a rotable combined air intake and choke tube, k, fulfilling the functions of a throttle for the mixture and air supplies, is used in combination with an annular petrol nozzle, z, regulated by a screw-down valve, n. The action and form of this will be seen to somewhat resemble that shown in fig. 31, in so much as at starting, and while running quite slow, petrol will rise above the annular nozzle until it covers the lower end of the tube, s, when, with the rotable choke tube

recommended for ordinary touring speeds on the level, leaving the third in reserve for hills and for higher speeds The control



FIGS. 36 and 37 Triple jet carburettor with rotary slide throttle control shown in full open, starting, coasting, and closed positions.—Huggins & Parker

is somewhat analogous to a three-bar switch controller on a tram-car, the motor responding instantly to the throttle opening The beauty of this carburettor, known as the H.P., is its absolute simplicity, the rotary throttle lending itself to a more unique

design than one with a balanced piston control, as shown in fig. 29, for instance, or for a separate wing or lift-valve throttle for each tube Again, by having a larger diameter throttle a fourth jet can be used, thus obtaining a more graduated control.

In the Polyrhoe multiple-jet carburettor an almost infinite graduation is attainable, but not by a series of nipple nozzles, as these would take up too much room. The method adopted is to place a finely slotted thin brass sheet between two plain sheets clamped together the bottom edge of these dips into a channel in connection with the float cistern, while the top opens into an elongated air channel leading to a cylindrical mixing chamber. Traversing this there is a piston, which is connected to another piston of larger diameter by a hollow trunk. by this means the depression caused by the opening of the mixture throttle (in this case a graduated piston) is communicated to the remote end of the controller piston, and thus causes it to move towards the closed end of its cylindrical guide, and in so doing uncovers the elongated air channel serving as an induction or deflection passage for the petrol jets, to a more or less extent, according to the throttle opening As there are as many as twenty to thirty narrow slots in the nozzle plate, and as each slot on being uncovered by the automatic air and petrol supply piston forms a tiny jet, the volume of mixture formed is not only in very close ratio to any varying depression, but almost exactly constant. (The regulator is of course drawn back by suction against a spring.) Obviously it would occur to a designer · Why not dispense with the automatic piston regulator and arrange for the nozzle comb and air-induction slotway to be uncovered direct by a hollow piston throttle, somewhat as shown in fig 29? For answer to this suggestion · It has been done, but was not found to respond so sensitively while running with the motor heavily loaded, as on an up gradient on top gear, the regulator then pulsating to the throb of the pistons, therefore in this instance, part automatic is an improvement on direct mixture control, under ordinary running conditions

(9) *Unclassified carburettors* Of these, as would be expected, there is an increasing number, bearing in mind the diversity in principle of carburettor design, the application of petrol motors to so many purposes; the difficulties of perfect

carburetion; the fact that fully 5,000,000 carburettors are now in use, that during the past ten years more than 6000 patents have been applied for, and over 5000 issued, in this country alone, that throughout the world there are over 600 factories engaged on the supply of petrol motors for aero craft, cycles, marine craft, road cars, and for general stationary work; and that for all of these purposes the motors require carburettors.

With the introduction of newer ideas many carburettors once to the front are now more or less in the background such is the penalty of unremitting endeavour and as time goes on others will follow as a matter of course, but what exactly may be the trend of carburettor design just now is very uncertain, unless it be for multiple jets and more definite control!

Then again, for many purposes, "What is good enough" is better than the more perfected design, therefore it is only reasonable to suppose that the tendency in the future will be for specialised designs for different purposes

For instance, the Convac carburettor, shown in fig. 38, is a specialised combination design in part coming under categories 2, 4, and 6 for purposes such as electric lighting, for which a very perfect regulation is desirable In this there is a blend of contra effects, as when the air plunger, *a*, is down on its seat, as in starting and running unloaded, with the throttle nearly closed, the combined effect of depression and induction on the jet issuing from the nozzle, *z*, can be modified by reducing the pressure in the float cistern to the depression in the mixing chamber by means of a pipe connection, *c*, to the fixed tube within the convergent nozzle forming part of the air plunger, *a*, again, that as the air plunger is drawn up by the increasing depression following a further opening of the mixture throttle, the depression in the float cistern will be reduced until, with the air plunger in its highest position and throttle fully open, although the depression in the mixing chamber may be 4 or 5 in., there will be little or no depression on the surface of the petrol,—therefore a very facile adjustment of opposing forces can be made by the vent cap, *c*. As with all gravity-closed air regulators a choke passage is provided, as at *j*, to damp out oscillation, and as there is no other adjustment excepting the vacuum cap, *c*, a carburettor of this design, properly proportioned and constructed,

lends itself for being easily tuned to the particular running conditions required.

The Rayfield is another variant from either category, being of composite design, in which the air is supplied under three separate controls: one, as at starting and running slow unloaded; another brought into action simultaneously with the further opening of the mixture throttle (category 7), the two valves being interconnected, while the third is automatic, and

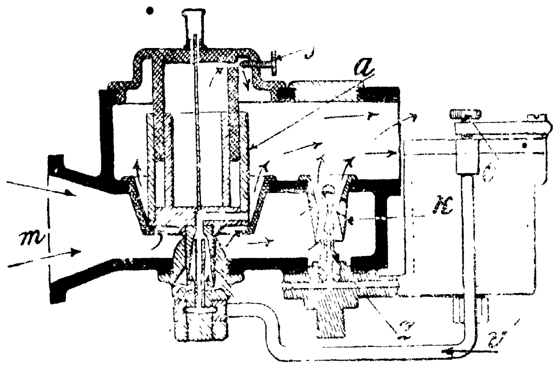


FIG. 38.—Variable-pressure single-jet carburettor with gravity-suction air control—Convac.

opens only when the depression exceeds a predetermined limit, as at high speeds. In addition to the triple air control, the petrol supply is variable by means of a finely-tapered nozzle regulator, interconnected with the mixture throttle, each of these supplies being separately and collectively adjustable with the single-control rod connected up to the steering wheel.

In regard to the Sthenos carburettor, shown in fig. 39, this cannot be classified under any of the categories named, as it has no automatic means for regulating the quality of the mixture supplied, other than by the auxiliary nozzles, x, whose function at starting and while running unloaded, with the plug throttle, h, with portway in the horizontal position (shown in dotted lines), is then to divert the jet from across the nozzle by

means of a rapid flow of air, the through-way of the throttle being then closed. Now on turning the plug to the position shown, the jet and air will be drawn straight through from nozzle, z, and choke tube, k, the auxiliary nozzles, x, being then put out of action; but in any intermediate position the relative

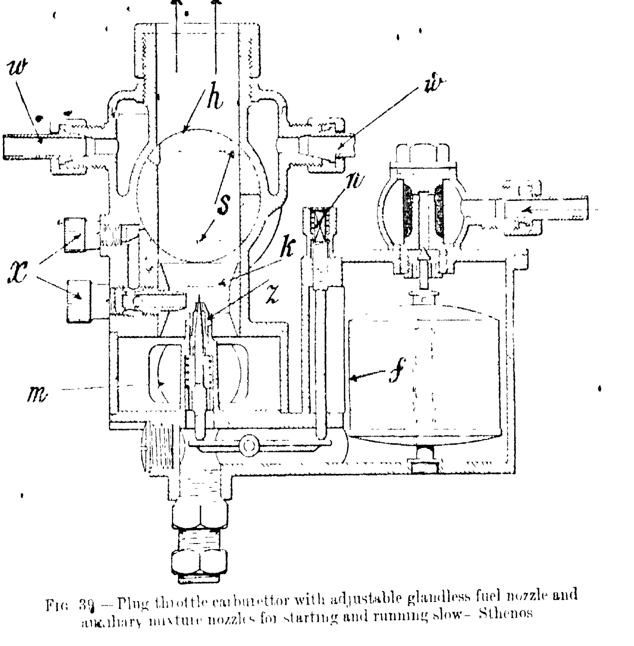


FIG. 39.—Plug throttle carburettor with adjustable glandless fuel nozzle and auxiliary mixture nozzles for starting and running slow—Sthenos.

volume of spray mixture diverted from the straight-through flow will vary according to the angle of the throttle port, the method being to increase the horizontal flow across the nozzle point, and thus wipe off a supply of petrol, when the vertical flow through the choke tube would have an insufficient inductive effect. For this purpose the level is maintained at the apex, which is broad, and caused to be annular by the taper plug. Entire reliance for varying the mixture is placed on adjusting

the opening of the nozzle by the screw, *n*, this, by the way, is a good feature in itself, as by this means a gland at the bottom of the feed screw is eliminated, springs are also provided, so that the most minute adjustment of the screw, *n*, will alter the jet. The action of this carburettor will thus be seen to be not simply a variant of existing practice, but to regulate the mixture on a method radically different from any other.

In the Welsh carburettor a constant mixture is supplied by a method based on the theory of differential momentum values. The air column is about sixteen times longer than the column in the petrol nozzle to balance the two fluids. The idea is that by utilising this principle any very slight difference in the air flow, due not only to speed of the motor, but also to varying velocity of the pistons, is communicated to the petrol feed, thus obtaining an almost infinitely perfect mixture. The effect of friction of fluids of different densities is also utilised to correct carburetion at different temperatures of the atmosphere. The carburettor, however, is exceedingly simple and consists of two small mixture tubes arranged side by side in the centre of the petrol cistern, with a concentric float fitting around them. Into these two choke tubes a series of small nozzles, each very short, project. The bottom ends of the mixture tubes lead into a throttle casing, and are opened progressively by a part rotary movement of a segment throttle. The feed can be minutely adjusted by a dialled setting to put jets of slightly different size into communication with the tubes.

In all carburettors heat must be supplied to compensate for that absorbed during the process of evaporation of the jet, for without this the surface adjacent to the jet will eventually become coated with ice, caused by the moisture in the air, and the exterior of the carburettor will become white. *Apropos* of this, the writer who in an experiment made with a three-cylinder 7-in × 8-in. vertical launch engine, having a carburettor, as shown in fig. 12, found that the whole thing got so solid with ice after twenty minutes' running on full throttle that the engine stopped. On quickly taking the parts adrift, the mixture pipe (1 75-in. bore) was found reduced to 0 8 in., and the mixing chamber almost solid, this was with Pratt's gasoline, sp. gr. 680, which is, of course, much more volatile than the heavy motor

spirits now obtainable. this shows, however, that even with the most volatile petrol heat must be supplied, not necessarily to assist evaporation, but to prevent the moisture contents of the air from freezing.

There are two methods of supplying the heat necessary to prevent condensation, and also to assist in the volatilisation of petrols of mixed composition: one, by jacketing the carburettor (shown in figs. 15, 21, 23, 25, 27, 28, and 29) and connecting it by two small pipes either to the cylinder jacket or to the exhaust. As to preference in this if the motor is to be worked in a climate not falling below freezing point there is some advantage in the hot-water method, especially in motors having the exhaust pipe on the opposite side to the carburettor, but as the difference in effect is very slight, it resolves into a matter of expediency rather than of efficiency, one advantage, however, in the jacket method is the elimination of the air pipe (shown in figs. 15, 16, 17, 25, 27, 28, 30, 32, 36, and 37) and thus makes for a neater construction. Indeed, in some carburettors there are so many air inlets that to connect only the primary supply to a pipe, unless for the purpose of preheating the air, would be inconsistent. therefore to have both an air pipe and a jacket is unnecessary. The advantage of the air pipe, if used alone, is that it lends itself conveniently for temperature control, it being usual to draw from a sleeve over the exhaust pipe when starting and running easy, and to admit air direct by some simple form of shutter or wing valve when on full load, this being connected to an indexed control; this is rather a good plan, as some low-grade petrols require a higher temperature than others, but in general practice the cooler the mixture the better the running when on full load. Although not necessary on either an automobile or a motor boat, an automatic device for regulating the temperature is useful on motors required to run on a variable load unattended, as in driving a dynamo, and to that end the method shown in fig. 40 has been devised. This consists of a corrugated cylindrical case, *c*, containing a liquid boiling at low temperature, such as alcohol, and placing this in a chamber open to the exhaust. one end of the expansible case is fixed and the other connected to a flap valve, *d*. On the exhaust exceeding a predetermined temperature the

fluid will expand to such an extent as to open the flap and thus admit cold air, and again, when running on a light load, with the throttle partly closed by the governor, the temperature of the exhaust will fall, the case contract, and the flap be partly closed, automatically putting the carburettor into connection with the hot air supply; thus by accurately proportioning and carefully adjusting the essential components of this device it

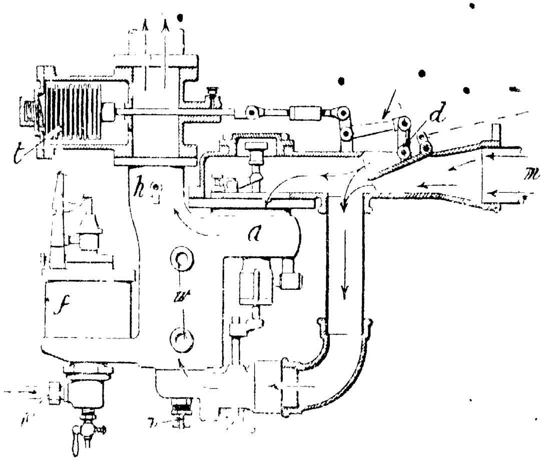


FIG. 10. Induction carburettor with automatic temperature control—Lund.

would seem to be possible for an even temperature to be automatically maintained over a wide range of load.

That two-stroke petrol motors have not held a position in the front line is a little disappointing to many, especially as the two-stroke principle has been turned to such good account for both gas and fuel-oil engines of large power; this is the more surprising, as their construction is so simple relatively to the cam-valve four-stroke motor so largely adopted for cycles, motor boats, and other purposes. In practice, however, their simplicity is more than offset by a greater consumption of both petrol and lubricant, coupled with their inability for that wide range of speed control now in general demand. The principal reason for this is the

method of pumping a mixture of petrol and air, either through the crank chamber, or by an extension of the motor cylinders, which in any case is forced into the power cylinder while the crank is turning round the outstroke centre, the mixture being in part deflected by the piston to prevent it passing out with the exhaust At a critical speed such motors can be made to work tolerably well, but when the speed falls below that for which the inlet and outlet port openings have been designed, more or less of the petrol mixture escapes with the exhaust; and again, at higher speeds the tendency is for the inert gas to be retained, this is why two-stroke motors cannot be run at high speeds with a high efficiency. Now, in the A. E Scholes motor (Hunt & Co, Millwall) the power cylinders are first thoroughly flushed by a charge of air, and then, but not till after the exhaust outlet is closed, a charge of petrol mixture is forced in. The flushing charge is constant for all speeds, and is not affected by the control plug used for the mixture supply, thus there is no loss of petrol with the exhaust under any circumstance whatever. This *modus operandi* will obviously suggest the use of either two sets of compressing pumps, or a set of petrol-injection pumps, —but neither is required The method adopted is to divert a controllable part of the air from the compressors (in this case the front ends of the power cylinders) through a specially designed carburettor, as shown in fig. 41, this, consequently, works under constant-pressure variable-volume conditions The air from the pumps (in this case three) is forced in at *a*, hence either the whole of it, or only such quantity as required for the particular running condition, is forced through the con-divergent nozzles, *k*, *r*, to the chamber, *d*, and thence *via* the return pipe, *t*, portway, *h'*, to the inlet manifold, *m*, of the power cylinders To reduce the power the controller, *r*, is turned, so that a portion of the air entering at *a*—which, it should be borne in mind, is always at constant volume—is diverted direct to the manifold, the port opening being indicated on the dial, *l*. Petrol is supplied at constant level to the float cistern, *c*, from a pressure tank connected up by the pipe, *s*. The pressure in the cistern is always in equilibrium with that of the air supplied at *a*, as it is connected thereto by a large balancing pipe, *b*. Petrol is drawn up the tube, *p*, by induction,

fluid will expand to such an extent as to open the flap and thus admit cold air, and again, when running on a light load, with the throttle partly closed by the governor, the temperature of the exhaust will fall, the case contract, and the flap be partly closed, automatically putting the carburettor into connection with the hot air supply; thus by accurately proportioning and carefully adjusting the essential components of this device it

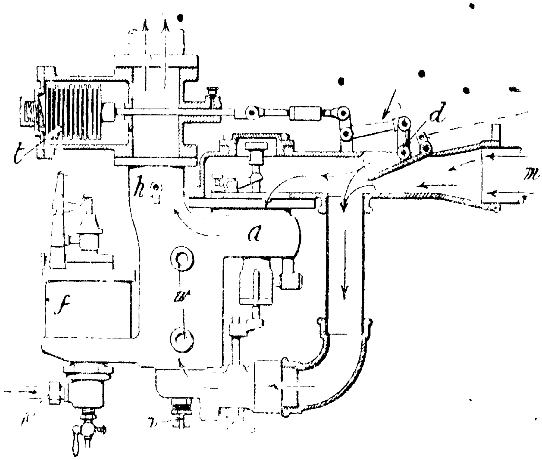


Fig. 10. Induction carburettor with automatic temperature control—Lund.

would seem to be possible for an even temperature to be automatically maintained over a wide range of load.

That two-stroke petrol motors have not held a position in the front line is a little disappointing to many, especially as the two-stroke principle has been turned to such good account for both gas and fuel-oil engines of large power; this is the more surprising, as their construction is so simple relatively to the cam-valve four-stroke motor so largely adopted for cycles, motor boats, and other purposes. In practice, however, their simplicity is more than offset by a greater consumption of both petrol and lubricant, coupled with their inability for that wide range of speed control now in general demand. The principal reason for this is the

engine on benzoline (sp. gr. 700), much importance was attached to the fact that the engine could be also run on gas, and without the slightest alteration, since when many engines, vertical and

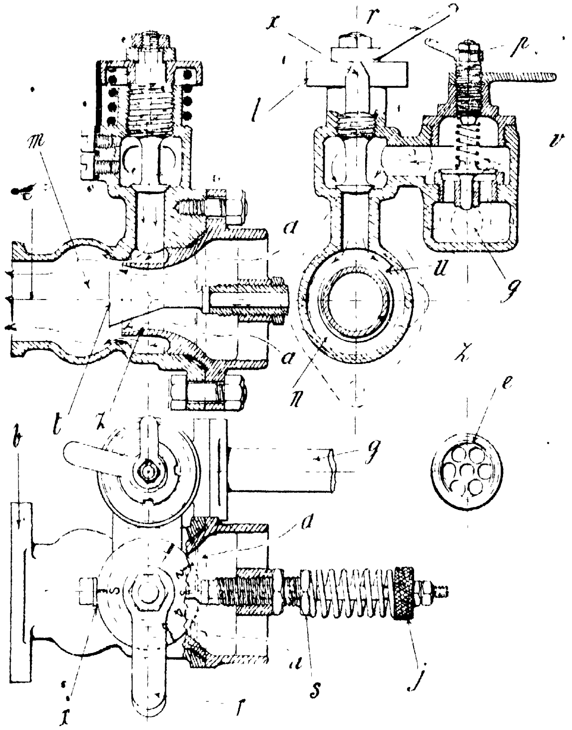


FIG. 42.—Auxiliary gas mixer with automatic control, suitable for attachment to any ordinary make of petrol carburettor—Butler.

horizontal, have been constructed to his designs to run on either gas, petrol, or paraffin, according to the exigence of the moment, the change over from one fuel to the other being instantly feasible on full load. Illustrations of the apparatus used for this are shown in the next chapter, while that in fig. 42 shows

the application of this carburettor—which, as explained, is based on the inspirative principle—as an auxiliary attachment to an ordinary petrol carburettor. All that is necessary is to attach it to the main air inlet and connect up to the gas container by a pipe, *g*. An essential feature of this mixer is the strong induction effect of the annular feed, *u*, and venturi nozzle, *z*; another is the automatic valve, *v*, which can be set by the regulator, *p*, to suit any slight difference of pressure in a flexible container or as supplied by the reducing apparatus from a compressed-gas receiver. The gas to the motor is regulated by the feed-valve handle, *r*, the valve stem being provided with an indexed dial and pointer, *x*; there is also a spring under the dial for taking up all slack in the threads and for holding the setting of the feed, which is important. The mixer can be attached to the main air intake of the carburettor either by a flange, *b*, or by an intervening connection as more convenient; the bore, *c*, should correspond to that of the air intake. A compensating plug, *t*, is used to adapt the bore of the venturi nozzle, *z*, to the exact running conditions, and may be locked in position for running on gas only; although when the mixer is required to serve as a combined petrol and gas carburettor, and is provided with a second feed valve leading to the annulus, *u*, the plug, *t*, must be fitted as a pulsator and be provided with a spring and pression adjustment as at *j*, so that the air supply shall be automatically regulated to the petrol feed at different speeds and throttle opening.

In consequence of the sudden big demand by owners to have their cars converted to run on gas, it is not to be wondered at that many crude methods have been adopted, a gas auxiliary feed lending itself in a more or less makeshift manner, by simply connecting the supply pipe either to the main air intake or just below the throttle. By such a method it is obvious that although the feed can be set to suit the average speed of the motor, the feed when running slow will be much in excess of the requirements, and will be inadequate when opened out for heavy pulling. No wonder, then, that one so often sees a van struggling along on slow gear, when with a properly proportioned mixture it could be driven on top. True, with gas there is a wider range of feed than with petrol, but, even so,

it has been conclusively proved to be uneconomical to regulate an engine by the gas feed alone with the air supply at constant volume, conversely, it is also bad practice to regulate the volume of mixture unless both gas and air are varied together, thus it is obvious that to allow the gas to stream in the supply pipe under the unrestricted pressure of the container, the mixture, while possibly approximately correct at one speed, will not be so at any other, and, worse, will be lean just when it should be rich—viz. on open throttle.

As to the relative values of gas and petrol, naturally, volume for volume there is an enormous discrepancy, for whereas 1 lb. of gas will occupy 33 cub ft., it will require from 230 to 240 cub. ft. of gas to be equal to 1 gallon of petrol (sp. gr. 700 to 730), and as many brands of motor spirit exceed this density, the gas equivalent in such case must be taken at a proportionately greater volume. The calorific values of gas vary slightly according to the quality of coal and process of distillation but may be taken as approximately 620 B.Th.U. per cub. ft. at 60° Fahr. Temperature is more important than with petrol, for whereas a difference of 10° will only have an effect on a volume of 2 gallons to make this measure one-sixth of a pint, more or less than 16, 10° difference in temperature on a volume of 480 cub. ft. of gas, which is the equivalent of a 2-gallon can of petrol, at 60° Fahr. will make this measure 9 cub. ft. more or less, according as the temperature is higher or lower, thus with the temperature at 40°, the calorific value of gas supplied will be 5 per cent. greater than at 70°, although of the same volume as indicated on the meter. However, this is not a point of much importance; what really matters is the excessive leakage that sooner or later occurs in the container due to the rapid deterioration of the fabric.

CHAPTER V.

PARAFFIN VAPORISERS.

FOR many years, following the practice first inaugurated in Pennsylvania of drilling for oil (1859), the most profitable constituent of crude petroleum was the distillate known in America as kerosene and as paraffin in this country, this being the second series coming over from the "still" during the preliminary process of distilling the oil in its crude state. The first series are the benzines, etc., now so valuable for motor sport which until the discovery of their great advantages for high-speed engines were generally considered as being of insufficient value for barrelling. The lamp-oil series owes its name to the fact that crude oils containing paraffin wax, known as the paraffin series, in contrast to other oils containing asphaltum, give off a higher percentage of distillate of such nature that when subjected to various processes of re-distillation and refinement are found so valuable for wick lamps in use all the world over. This product is a more or less pungent pale blue or straw-coloured, limpid, and very penetrating oil of about 0·8 the weight of water (ranging between sp. gr. 760, daylight; 780, tea-rose; 800, rock crystal, 840, russolene, etc., according to the grading and origin of the oil). All these show only a slight trace of inflammable vapour unless heated to a temperature higher than 100° Fahr. (83° closed test). The legal test regulation varies a little above or below this in different countries, according to climate requirements; oils flashing under 800 are not considered suitable for the tropics, and are not generally used for ship lighting,' indeed, for coast lighthouses and lightships there is a special brand, known as Trinity House,

that has a flash-point of 150° close test, in which oils all the more volatile elements are thoroughly distilled out, leaving a product of more even composition. Since the increasingly great demand for petrol arose, newer processes have been evolved, by which most of the lighter paraffin oils are split up and thus lose their more volatile elements. The method adopted is to steam-heat the oil to a high temperature, when the resultant vapour is condensed and returned for re-evaporation for such a period as found necessary for a more or less general molecular reconstruction, known as "cracking." By this means the percentage of motor spirit can be considerably increased, and, in consequence, a new grade of paraffin oil is produced having a higher density and flash-point. This is explained at considerable length in *Oil Fuel: its Supply, Composition, and Application.*[1]

For power purposes paraffin oil can be used in a variety of ways: in a series of blow-flame burners for raising steam, or in one of many vaporising processes used in connection with internal combustion engines, in all of which the oil itself, or a mixture of spray and air, must be heated, either by surface contact or by superheated air.

Paraffin, unless very finely comminuted, cannot be ignited, like petrol, in a motor cylinder without some heat-treatment. There are a number of vaporisers in use, all of which may be included under two categories: one, those adapted to the ordinary form of gas or petrol engine without alteration to the cylinder; the other, those that require a special form of combustion chamber and feed mechanism for each cylinder of the engine.

Of these, category 1 may be subdivided into two classes, viz.:—

(1) External "exhaust-heated" vaporisers.

(2) External "flame-heated" vaporisers.

And category 2 also into two classes, viz.:—

(3) Vapour-feed jacketed vaporisers forming part of the cylinder head.

(4) Injection-feed unjacketed vaporisers, also forming part of the cylinder head.

[1] *Oil Fuel: its Supply, Composition, and Application*, by Edward Butler, M.I.Mech.E. (Charles Griffin & Co., Ltd.).

Exhaust-heated Vaporisers.—*Class I.*—Although carburetted air, spray injection, and jet atomiser petroleum-spirit engines had been in use on the Continent since 1880, and still continue to be used in America in considerable sizes for ordinary stationary purposes, it was not until five years later that attention was centred on adapting an engine to run direct on paraffin as a self contained unit. Humes then took up the problem in association with the firm of Priestman Brothers in collaboration with Etève, to modify the latter's compressed-air petroleum spirit carburettor as a paraffin vaporiser. In this the same method of atomising by a compressed-air jet (shown in figs. 43 and 44), by Etève, was used in combination with an exhaust-jacketed chamber patented in 1885 (8411). Factors of import-

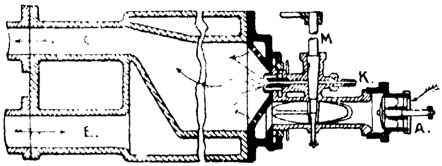


Fig. 43. Humes-Priestman-Etève exhaust-heated compressed air atomiser paraffin vaporiser.

ance in vaporising successfully the heavier grades of paraffin oils, such as those used for coast siren compressors, for instance, are the atomiser and combined oil and air regulator, M, under governor control. Air at from 10 to 15 lbs. pressure is supplied to the annulus surrounding the central spray nozzle, to which the paraffin feed is connected at K from a tank at the same pressure. A wing valve on the oil-regulator plug stem simultaneously controls the diluent air, a back-flow interceptor being provided at the inlet, A, for the reason that whereas the mixture admission along C is intermittent, the spray and atomising air is continuous. A great number of these engines were installed for pumping and electric-light work during the period 1888–1900, a small engine of this make being exhibited at the R.A.S., Nottingham, in 1888, and another, which was then without a competitor, was awarded a prize at Plymouth two years later. However, since the Cambridge trials in 1894, where seventeen

engines of eight different makes were shown in open competition, the Priestman engine, owing to its cost and complexity, found itself less and less the vogue, notwithstanding its remarkably smooth and regular running.

In the Griffin engine, brought out some years later, a modified form of the same type of vaporiser was used. In this (figs. 45 and 46) a mixture of paraffin oil and air was sprayed under pressure into an exhaust-heated chamber of similar construction, the illustration (fig. 45) showing one adapted for a two-cylinder marine engine. A feature in this vaporiser is the hand-wheel clamped cover at the exhaust end for gaining easy access to the corrugated inner chamber to clean out deposit. Another is the atomiser (fig. 46), in which oil and air supplied at 10 to 15 lbs. pressure is sprayed from a nozzle, as in fig. 44, excepting that the oil is led into an annulus surrounding a central air jet supplied from a pump to the connection, D. Air enters at the end openings, A, leading direct to the inner corrugated chamber, where it mixes with the atomised spray regulated by a plug, K, thence the vapour and air mixture flows *via* the outer jacket, together with a further supply entering through the shutter valve at the side. Between the air jacket and the exhaust there is a small communication to allow a little of the exhaust to mix with the air, for the purpose of damping down the tendency for paraffin mixtures to detonate when used in engines running under full load, this tendency increasing both with size of cylinder and compression.

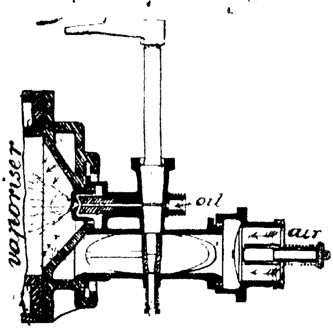


FIG. 44.—Details of Humes-Priestman spraying nozzle and regulator.

The next earliest paraffin-oil engine to the Priestman-Etève was the Smyers, introduced from Belgium in 1887 by Bryant Donkin. In this there was an exhaust-heated chamber, from which the engine aspirated its supply of vaporised paraffin and

air mixture as in an ordinary gas engine constructed to work on the "charge-cut-out" governing system as then used in all gas engines. The charges of paraffin were injected into the vaporiser by a pump, which was put out of action in synchronism with the admission valve.

The vaporising method patented by the writer (No. 6990) in 1890, and now generally adopted in all high-speed paraffin motors of the electric-ignition type, for motor boats, lorries, tractors, and motor ploughs, as well as in the numerous high-speed stationary engines of small size was designed to start cold on benzoline (the equivalent of petrol as now understood), and to ignite by a high-tension spark generated by a bichromate paste battery and coil Two engines on this system were

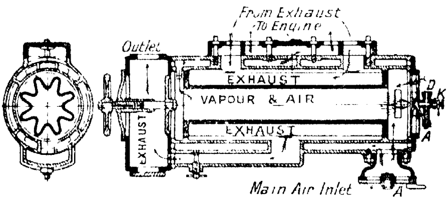


FIG. 45.—Griffin exhaust-heated compressed air vaporiser.

entered at the Cambridge R A S trials in 1894 by Clarke-Chapman & Co, one a 7-in. × 12-in stationary engine rated at 8 b.h.p., and the other a 16 b h p portable "*self-starting*" engine, with a 10-in. × 16-in. cylinder. At this period, however, great prejudice was evinced towards electric ignition in its then stage of development, also towards the use of a non-flash-proof medium, however negligible in quantity, to start on. But *tempora mutantur*, and now motor spirit (petrol) is used for all sorts and sizes of engines, and is of far greater importance than paraffin. In these engines there is a small cast-iron cistern, holding from 1 to 4 pints of motor spirit in one compartment, and a feed float in the other for the paraffin supply at constant level; either, or both together, of the two fuels can be put into communication with the vaporiser by a two-way plug with indexed dial and pointer, so making it possible to start without any preliminary heating up, and to "*change over*" from

starting to running oil in from 1 to 1·5 minute, and after an hour's stop in less than half a minute. Curiously, at this time it was preferred to start by a blow-flame, even if it took an hour to get away, and by request a number of these engines were supplied with the vaporiser arranged to be heated by a blow-flame as an alternative to the change-over method: but in all cases, after an experience of the cleanliness and ease associated with the use of a small quantity of benzoline to start on, this more convenient method was preferred.

As shown in fig. 47, this change-over method lends itself equally well for using gas as an alternative, in which connection as it is an advantage to alter the compression, the small end of the connecting rod (wedge-block pattern) is fitted with two packing plates, both of which are taken out when permanently deciding to run on paraffin; one plate is left in when desiring to run on either fuel, according to the convenience or exigence of the moment, and both plates inserted when requiring to run continuously on town gas. This form of vaporiser is fitted with a small duct connecting the passage down the hollow-feed regulator with the exhaust, to suppress excessive violence of the explosions when using paraffin on full load; it is an advantage also to fit a bye-pass connection to short-circuit a portion of the exhaust direct to the outlet pipe, as the tendency when running on full load continuously is for the vaporiser to get overheated. This, however, can be neutralised by a water feed, as shown in fig. 47A, which illustrates the standard design of vaporiser for petrol-paraffin engines with cylinder over 9-in. diam. In this the engine is started on petrol, with the regulator, BN, opened, as marked on the dial, then after one minute or so the regulator, PN, is opened to the starting positions, also indexed on the dial,

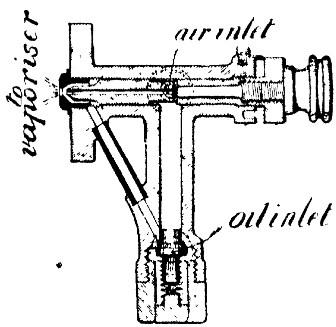


FIG. 46.—Griffin oil-spraying nozzle.

and for the next two or three minutes both are left open, BN during this period being gradually closed, and PN reduced to

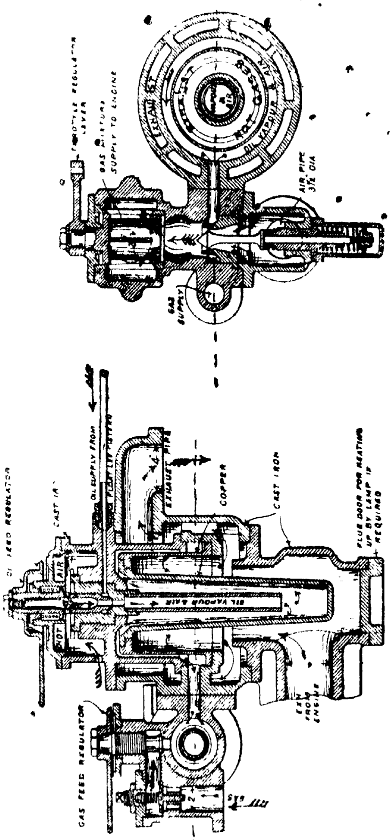


FIG. 47.—Butler exhaust-heated vaporiser, inspirator, and governor valve for self-starting 13½-in diam × 22-in combined oil and gas engine, interchangeable while running.

the running position. When on full load, and the engine begins to thump harshly, the regulator, WN, is opened until the thump is just perceptible; each of the three feeds is connected to a

float cistern. The neck of the inspirator, A, is surrounded by an annulus, into which each of the three mixture feeds communicates direct, the paraffin-atomised mixture by the passage, PV, leading to the well (PV, down which extends a pipe, so preventing the spray from shorting more direct to the inspirator.

To clean the vaporiser the cover is removed, thus exposing to view the interior of the well and the exterior surface of the inner chamber bonnet, but this is only necessary after 500 to 700

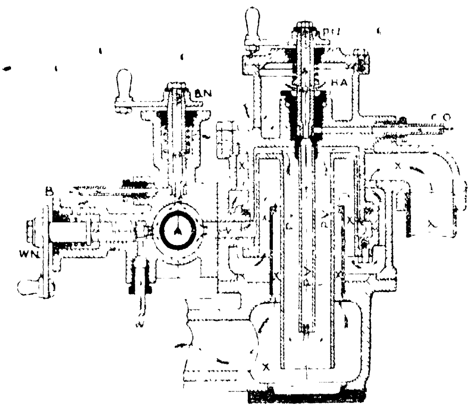


FIG. 47A.—Butler exhaust heated vaporiser for self starting petrol-paraffin engines of over 16 b.h.p., shown fitted with petrol- and water-feed regulators direct to the inspirator.

hours' running, thus in engines used only intermittently, this means once a year. In fact, engines of this design still in service after over twenty years' intermittent use are found to run longer than a year without cleaning out the vaporiser.

Exhaust-heated vaporisers, whether fitted with a compressed-air atomiser requiring an air-pump, as shown in figs. 43–46, or arranged on the induction principle to utilise the inspirative action of the motor piston to draw an atomised spray of paraffin oil and air into the vaporising chamber, are better adapted for two-, three-, and four-cylinder engines than those with a single cylinder, for the sufficient reason that one vaporiser, mixture throttle, and set of fuel cisterns suffice, which remark also

applies to vaporisers of the compressed-air atomiser type. Of these two systems, those designed to work with an induced jet are more applicable to the numerous purposes for which a high-speed motor of the electric ignition automobile type is in such demand—*e.g.*, for motor boats, field and road tractors, motor ploughs, road cars, small electric-lighting and pumping installations, as well as a number of other purposes for which an easily started, economical engine requiring but a minimum of space is so peculiarly adapted.

Subjoined are lists of the more prominent makes of high-speed petrol-paraffin engines:—

For motor boats (British):—Barcar, Blake, Boulton & Paul, Britannia, Craig, Daimler, Day, Djinn, Forth, Gardner, Kelvin, Langdon, Maudslay, Max, Napier, Parsons, Phœnix, Rover, Russell & Newbery, Smart & Brown, Strickland, Taylor, Thornycroft, Tyler, Wolseley.

For marine motors (American).—Buffalo, Caille, Harrison, Jager, Loew, Standard, Wolverine.

For general purposes, including field tractors (British):—Alldays & Onions, Allsop, Aster, Bryant, Bumpstead & Chandler, Crossley, Fowler Keighley, Lindsay, Marshall, Martin, Pelapone, Perkin, Petter, Price, Rational, Saunderson & Gifkins, Walsh & Clark.

For general purposes, including field tractors (American):—Aultman, Avery, Bates, Bullock, Case, Emerson, Ford, Holt, Ivel-Hart, Mogul, Monarch, Overtime, Rumeley, Sandusky, Titan, Wallis.

Besides these there are a number of makers who specialise in different forms of paraffin vaporisers of the external exhaust-heated types, such as the Barker, Binks, Blake, Butler, Contanesco, Cottrel, Davis, Haddon, Halliday, Hallett, Hamilton, Hayes, Mathews, Noble, Notax, Parsons, Remington, Rowlands, Secor-Higgins, Southey, Standard, Stewart-Morris, Vulcan, Westmacott, Wilkinson.

Paraffin vaporisers[1] of the exhaust-heated type do not burn out or deteriorate, are easily cleaned, and do not crack the oil mixture so as to yield a deposition of solids in the cylinder, and

[1] Fully illustrated and described in *The Vaporising of Paraffin for High-Speed Motors of the Electric Ignition Type.*

if used in combination with the inspirative feed method as first used on the Butler stationary and marine oil engines, require neither air nor oil injection pump, the paraffin being supplied direct to a small cistern kept at constant level by a float or overflow control. This system lends itself to quickly responsive action on the throttle by a governor-controlled mixture supply. An atomised spray of water, or diluent of inert gas from the exhaust, can also be fed into the mixture supply in proportion to the volume of air used, in the automatic and simple manner adopted for working on mineral spirit at starting, the water-feed is useful for enabling a higher compression to be used and heavier loads carried without pounding, and gives a decided advantage in engines of large power, provided the water is sufficiently pure not to leave a deposit in the explosion chamber; a well-regulated water-feed results, moreover, in a more even and perfect combustion of the mixture, and prevents that violent detonating effect produced in the cylinder of a paraffin-oil engine working with a heated volatilised mixture combined with high compression when on full load.

Exhaust-heated vaporisers of the induction type are unquestionably the most suitable for the high-speed electric ignition type of motor, owing to there being no change required in the construction of the combustion chambers and valves; one jacketed chamber is, moreover, conveniently applicable to two, three, or four cylinders in a motor working on the four-stroke cycle; and as the vaporiser can be heated up by running the motor for a minute or two on petrol (the change over from petrol to paraffin presenting no particular difficulty), this makes it possible to run on paraffin under almost identical conditions as on petrol provided a properly designed vaporiser is used: in all of these, however, careful manipulation is demanded to get within 10 per cent. of the power obtainable on petrol. The drawback to the use of the flash-proof commercial brands known as lamp oil, paraffin, or kerosene, is the almost impossibility of obtaining a perfectly clear exhaust when running under the various conditions inseparable from the working of an automobile on the road. This imperfection in combustion of the mixture is not, however, of such consequence in a motor for field use and the many agricultural purposes for which there

is an increasing demand at home and abroad; nor does it materially prejudice the use of paraffin in small marine motors of high-speed electric ignition type.

A modified exhaust-heated vaporiser (one of the earliest of the automatic induction type with jet atomiser, first introduced by the writer) is shown in fig. 48, adapted for preliminary warming up by a lamp, for which purpose a flue-door is arranged underneath. In this vaporiser (constructed for a double-cylinder auto-marine motor)[1] the same general design is followed as in the preceding examples, adapted for engines of larger power (figs. 47 and 47A), except that the exhaust chamber is surrounded by a jacket to heat the air used for the central atomising jet. As the supply of cold air flowing through the venturi nozzle is reduced by the automatic air plug to practically nil when the motor is throttled up to run empty (the proportion being inversely as the speed), the motor is by this means capable of running steadily and continuously at reduced loads and instantly responds to the throttle without staggering when opened out.

Since 1893, when Clarke-Chapman & Co. fitted a 3-ton launch (which plied on the Tyne for many years) with an 8-in. × 8 in diagonal self-starting and reversible petrol-paraffin motor of the writer's design, exhaust-heated paraffin vaporisers have appeared in considerable numbers from time to time, for some of which most extravagant claims have been advanced, such as "smokeless exhaust," "non-chokeable" effect on motor valves and igniter, vaporiser "never" requiring cleaning, and, lastly, more power and perfect smoothness in running has been claimed for a motor fitted to run on paraffin than is possible with petrol! However, it is noteworthy in face of these assurances that up to the present there are so many offsets to the use of heavy oils in small cylinders that they have for the most part been found unsuitable for small pleasure cars, and are not very generally used in commercial vehicles. This is more to be regretted, as paraffin oil is so much cheaper and can be handled with greater impunity than the more expensive motor spirit.

The problem is an exceedingly difficult one, the speed, power,

[1] Fitted in a 15-ton yacht by Clarke-Chapman & Co., which made a non-stop run from Larne Harbour to Greenock in 1894.

and temperature varying so considerably. From the author's experience, after having experimented with and tested vaporisers

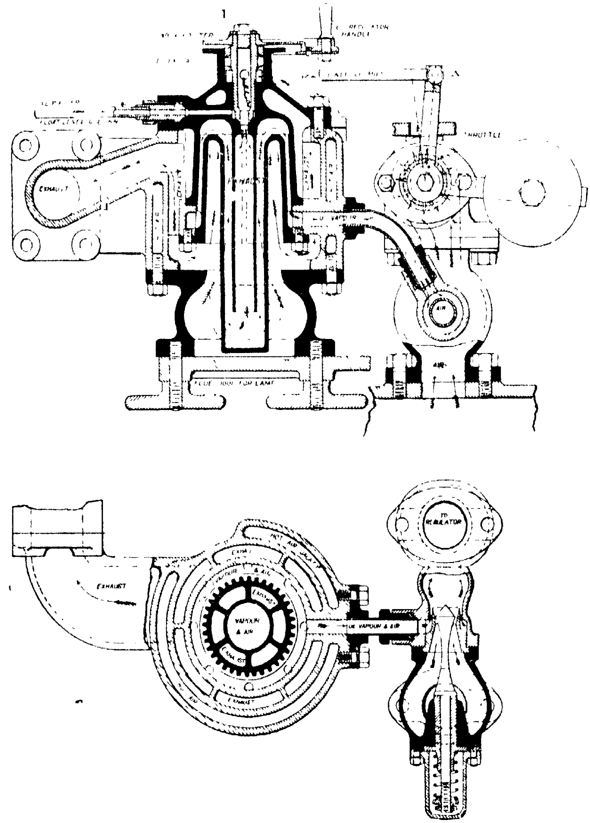


FIG. 48.—Butler paraffin vaporiser for twin cylinder (6 in. × 7 in.) marine engine, arranged to be heated by a blow-flame before starting.

of practically every known class, it would seem that for a multi-cylinder auto-motor of large power, whether applied for marine or other purposes, an exhaust-heated vaporiser, arranged

is an increasing demand at home and abroad; nor does it materially prejudice the use of paraffin in small marine motors of high-speed electric ignition type.

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The problem is an exceedingly difficult one, the speed, power,

[1] Fitted in a 15-ton yacht by Clarke-Chapman & Co., which made a non-stop run from Larne Harbour to Greenock in 1894.

an auxiliary current of air further sweeps out deposits of solids due to decomposition of the oil when the vaporiser is too highly heated. Obviously, no engines of very large size can be run with a vaporiser dependent on a blow-flame unless multiple burners are used, but as the burner is utilised to heat the ignition tube it thus suffices for engines capable of developing up to 16–20 b.h.p. with a single cylinder, and no attempt has been made to go beyond this. The advantage of the flame-heated vaporiser type of engine is the possibility of running on light loads with greater economy and more regular action than with those dependent on heat conducted from the combustion chamber or from the exhaust; such engines, in fact, approach very nearly in their working to the ordinary intermittent governed gas engine. However, although quite the vogue from 1893 to 1900, or thereabouts, they are now practically obsolete as a type; this is due for the most part to improvements in vaporisers, by which the blow-flame can be "put-out" after starting, so long as the engine is running with sufficient load to prevent it cooling below the temperature necessary for vaporising the charge. Another reason is the tendency for ignition tubes to corrode in continuous use, thus interfering with the timing of the ignition; the burners also are often found to require more than a proportionate attention, and are not suitable for engines exposed to draughts and wind.

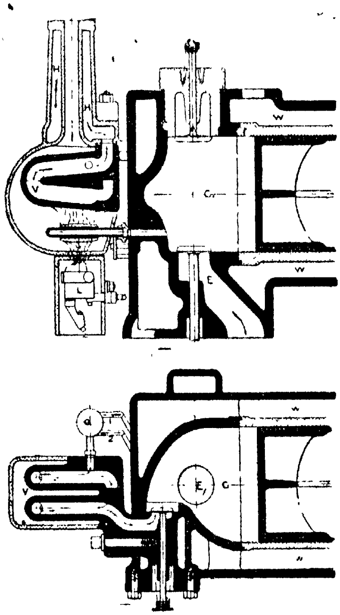


FIG. 49. Crossley's flame heated vaporiser.

The Crossley and Smith-Dudbridge vaporisers are arranged each with a syphon- or weir-flow feed-cup measuring device supplied by a pump from a tank forming part of the base of the engine. Paraffin oil is pumped into the cup in excess at each alternate revolution, and is emptied during the charge-admission stroke, so long as the engine does not exceed a predetermined speed. When running above this speed, as on reduced loads, the vapour valve (corresponding to the gas-admission valve in a gas engine) is cut out of action by the governor, and the valve does not open, no oil is then drawn into the vaporiser, and the next charge from the pump completely

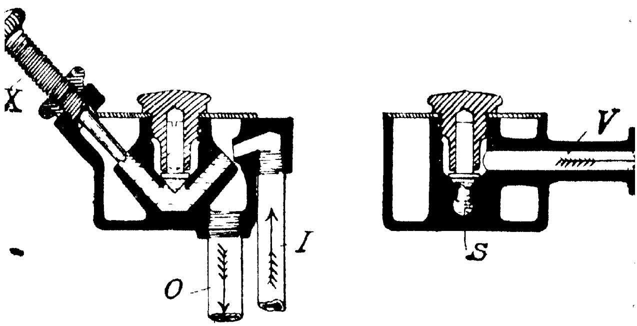


FIG. 50.—Crossley oil-measuring cup for flame-heated vaporiser.

overflows to the tank below. The Crossley vaporiser (fig. 49) consists of a casting bolted on to the inlet flange of the vapour admission valve opening direct to the combustion chamber. This casting has four transversely connected passages, V, one end being in communication with the jacketed chimney, H, for the hot-air supply, and the other to the vapour-admission valve casing. Oil is drawn in from the syphon cup, A, shown with feed and return pipes, 1 and 2. The blow-flame burner, L, is clamped on to the base of the cowl forming part of the jacketed chimney; this burner is fed from a small tank maintained at about 10 lbs. pressure by a small air pump. In this engine (one of which entered for the Cambridge trials in 1894 was awarded the second prize) the air-admission valve is automatic,

thus the combustion chamber, C, is scavenged at each "cut-out" stroke, this, of course, tends to cool the cylinder, but does not have a detrimental effect on combustion, owing partly to the fact that the succeeding charge is more completely vaporised and mixes with air free from inert gas. The measuring cup (shown in fig. 50) takes the form of a syphon, S, one leg of which can be varied in length by a plug screw, X; the surround-

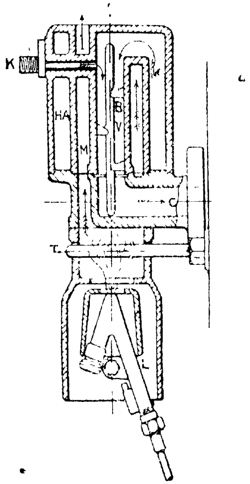


FIG. 51.—Smith-Dudbridge flame-heated vaporiser.

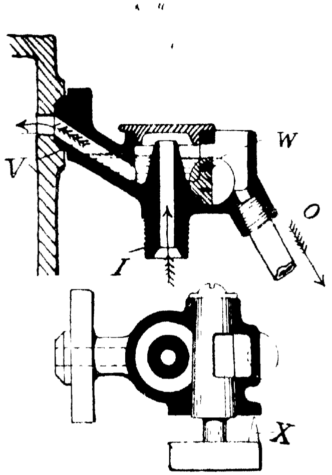


FIG. 52.—Dudbridge oil measurer.

ing sump is connected to the feed pipe, I, and drain pipe, O; forming part of the same casting is the feed passage, V, the flange of which is bolted on to the vaporiser just below the hot-air inlet. there is a non-return valve between the bend of the syphon, S and the passage, V, leading to the vaporiser, which is used to prevent overflow into V, during the periods between the charge admissions to the engine cylinder.

A somewhat similar construction has been followed in the Smith-Dudbridge flame-heated vaporiser, shown in figs. 51 and 52, the difference being more in form than principle. Here the heated gases from the burner, L, flow up the jacket, M,

partly surrounding the heated chamber, V, oil in measured charges is drawn in at K, and hot air from a flue, also partly surrounding the heated chamber, whence the paraffin and hot-air mixture is drawn *via* C, past a governor-controlled admission valve to the engine cylinder, and there mixes with the main supply admitted by an automatic valve. As in the preceding example, an ignition tube T, is arranged between the vaporiser and the burner, and a pump-filled measuring cup is used, but of modified form, as shown in fig. 52, where instead of a syphon, a weir overflow is used, by which the height and volume of the charge can be varied by the plug, W, to an exact degree by the indexed pointer, X. Oil is pumped in at each alternate revolution of the crank shaft through the geyser, L any overflow in excess of the working charge and all the oil pumped in succeeding a "cut-out" stroke returning to the tank *via* the drain pipe, O. There is no check valve required, as the level is always below the outlet of the fuel-feed duct, V, the basin is completely emptied at each charging stroke by the swirl of air indraught.

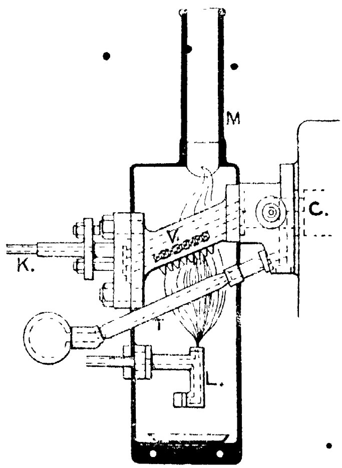


FIG. 53.—Howard flame heated vaporiser.

The Howard flame-heated vaporiser (shown in fig. 53) differs considerably from either of the foregoing in that the charge of oil (paraffin) is regulated by varying the stroke of the feed pump, which is cut out of action altogether by the governor in synchronism with the vapour valve at varying intervals, when the engine is working under full load. The charge of oil is pumped in at K, and after traversing a series of inclined passages, V, is drawn *via* C, together with a little air from a snifting valve at the side, past the vapour-mixture admission

valve to the cylinder. The ignition tube, T, between the burner, L, and the vaporiser is extended and provided with a bulb to ensure that inert gas is forced back beyond the heated zone of the tube, this is owing to the considerable length of duct between the open end of the tube and the combustion chamber of the engine.

A very simple form of lamp-heated vaporiser is shown diagrammatically in fig. 54, taking the form somewhat of an ordinary gas-engine ignition chimney. In this the space, V, between two castings constituting the vaporiser communicates direct with a cam-opened governor-controlled combined vapour mixture and air-admission valve in the casing inlet, C, which is held on its seat during "cut-out" strokes. The fuel feed, also under synchronous control with the admission valve, is supplied at K from a pump, a snifting valve, A, admits the necessary auxiliary air to the vaporiser, the main supply entering from a pipe below the heated mixture inlet to the admission valve casing. The ignition tube, T, extends upwards within the vaporiser chimney, and is heated by a blow-flame from an ordinary coil burner.

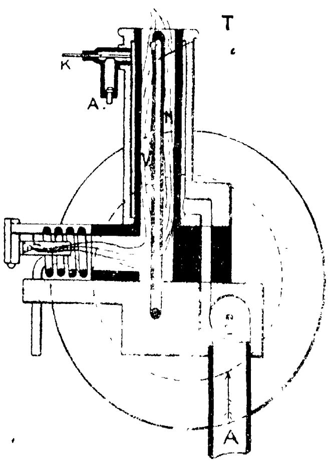


FIG. 54 – Carter-Blackstone flame heated vaporiser

In the Roots-Vosper flame-heated vaporiser, shown in fig. 55, paraffin is supplied in measured charges by a sliding grooved rod, P, from a hand-controlled gravity-feed inlet, K. This vaporiser is of the chimney type, with central burner flue, M; around the chimney are cast two series of cells, one for hot air to mix with the oil, this then being drawn along as indicated to the winding cellular passage around the chimney, M, whence the heated mixture mixes with a supplementary supply of cold

air entering at A, the amount being regulated by the plug, R; this mixture then enters the cylinder direct by the automatic admission valve, C. Many paraffin engines of small power, both in horizontal single-cylinder and vertical twin-cylinder design, having this form of vaporiser, were constructed in the period 1892-1900, before the advantages of the induction type of vaporiser with electric ignition were more generally appreciated. In this connection also it should be mentioned that an award was made by *The Engineer* in 1896 to a Roots motor fitted with this form of vaporiser applied to an automobile, this being offered as a stimulus to research in the production of a motor suitable for the propulsion of road vehicles that could be run entirely on paraffin oil.

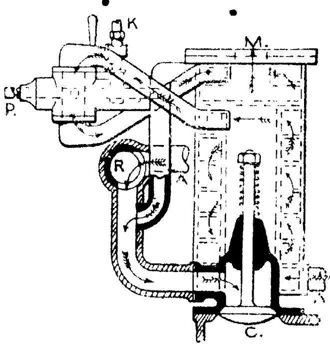


FIG. 55.—Roots-Vosper flame-heated vaporiser.

With this object in view, Messrs. Clarke-Chapman of Gateshead-on-Tyne also made a horizontal twin-cylinder, 5 in. × 5 in., motor designed by the writer to start and run on paraffin. This motor, which developed 8 b.h.p. and weighed 380 lbs., was fitted with a triple burner heated paraffin gasifier and electric ignition, but, owing to opinions expressed of its unsuitability for an automobile, due to risk of fire, and to the attention required by the burners, it was not entered for competition, and was afterwards used for another purpose.

The combination of electric ignition with a flame-heated vaporiser motor, however, has some advantages over one dependent on petrol for starting, in countries where motor spirit is difficult to obtain; also, for the reasons stated, a constant temperature vaporiser has other advantages, especially when a motor is required to run on reduced loads for a considerable time under circumstances where steady running and a clear exhaust are important factors. With this purpose in view, the Gardner paraffin motor has been evolved; this—made in

single-cylinder horizontal and multi-cylinder vertical form—is fitted with a separate flame-heated vaporiser[1] for each cylinder, constructed on the jet-induction system, with variable mixture supply to each cylinder under separate control. One feed tank supplies both the burners and float cisterns, and is fed from the main tank by an oil pump at constant level and pressure. In another vaporiser, known as the Hallett, and devised more specially for automobile and small electric-light motors, the necessary heating for "starting," and also for maintaining a more regular temperature while running on reduced loads, is derived from a resistance coil and electric current from an accumulator, charged by the starting and lighting dyna-motor when used for an automobile, and from the main current when used for a lighting installation. In this vaporiser the temperature can be easily regulated by hand or automatically, and is entirely independent of petrol and burners, and, what is more important, of the load on the engine as well, which is exactly what is wanted to ensure a clear exhaust when running light and to avoid overheating on full load.

There is another method of maintaining a more equable temperature in a vaporiser of the induction-feed type with variable mixture volume control, and this is to combine the constant heating effect of a burner—which can be also used to keep an ignition tube hot—with the inconstant effect of the exhaust, as shown in fig. 56, where paraffin is fed past a hollow screw-down regulator to the heated space between an outside exhaust jacket and an inside burner chimney with cross-tubes. A vaporiser of this design can be made independent of the exhaust for cylinders under 6-in. diam. if fitted with a separate burner for each cylinder, but for cylinders larger than 10-in. diam. it requires a bye-pass on the exhaust to enable it to shunt a variable volume of the hot gases direct to the escape pipe, the amount varying according to the load. The advantage, however, of a combined flame- and exhaust-heated vaporiser is that, should the burner fail, the engine can be kept going on the exhaust, when provided with electric ignition; also, with a combined heating effect, a single- or multi-cylinder engine can be run with greater economy at very reduced loads, even when deducting the oil consumed by

[1] Illustrated in *Vaporising of Paraffin.*

the burner. In this connection also it is appropriate to mention the G. W. Weatherhog paraffin-oil engine, patented in 1889

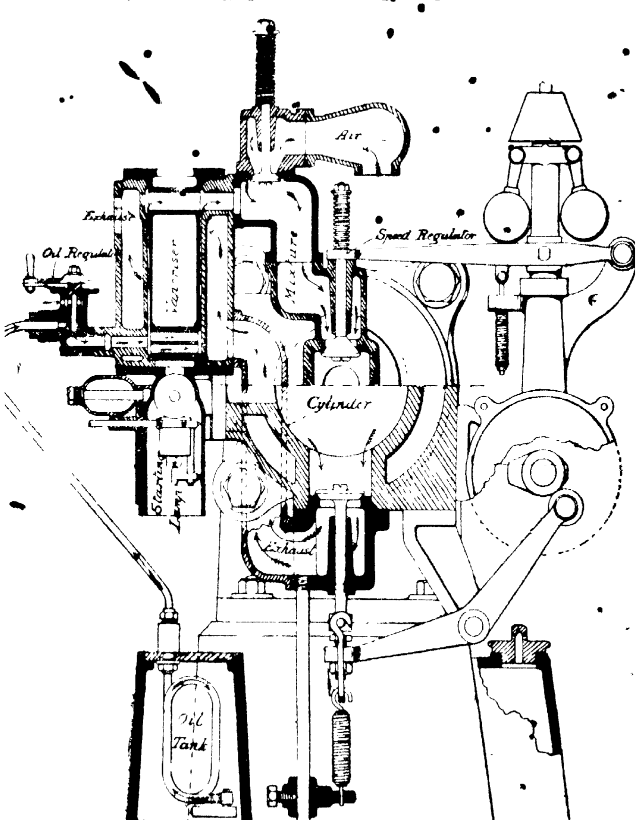


FIG. 56.—End sectional view of Allen-Barker paraffin-oil engine, showing combined flame- and exhaust-heated vaporiser, ignition lamp, admission, exhaust, and governor valves

(8013), and exhibited at the R.A.S. held in that year at Windsor, in which there were two vaporisers in series, one exhaust-heated

and the other flame-heated, the blow-flame being also used for the ignition.

Vapour-feed Vaporisers.—*Class 3.*—In this class—mostly used for single-cylinder horizontal engines of the industrial type and only adapted for the several brands of illuminating oil, known as paraffin—an extension of the combustion chamber is either itself jacketed or forms a jacket for a vaporising chamber, into which paraffin oil is fed by a pump or other measuring device. The necessary heat is either derived entirely from conduction and radiation from that portion of the combustion chamber of which the vaporiser forms a part, or partly from a flame, also used to heat an ignition tube All vaporisers of this class require to be thoroughly heated by a lamp, as from a blow-flame burner before starting, and usually so long as the engine continues to run on a light load, some engines being capable of keeping going on a quarter load and upwards without a lamp, while others do not work satisfactorily for long periods on loads much below half the normal rating.

One of the first attempts to make an engine work on paraffin oil was patented in 1887 (2783) by J. H Knight of Farnham, Surrey, whose first engine, made by himself in 1888, and further developed by Brown & May of Devizes, worked on the six-stroke cycle: this was to get rid of inert gases in the capacious combustion chamber, and partly to obtain a more reliable ignition with his blow-flame heated platinum wire carried by a slide-valve to the ignition port, the six-stroke cycle also allowed more time between the ignitions for heating. This engine was further developed by Weyman & Hitchcock, of Guildford and Cheltenham, and was known as the Trusty. It then worked on the four-stroke cycle, and was provided with an improved form of vaporiser partly surrounding an extension of the combustion chamber, a blow-flame heated tube igniter, and an oil feed by a pump which worked with a variable stroke from full down to one-third load, below which the feed was "cut out" by the governor. The illustration (fig. 57) shows a somewhat modified form of vaporiser introduced by Clayton & Shuttleworth. In this, access to the chamber, V, was very easily obtained, by removal of the end cover which carried the automatic igniter, T. As in the Trusty engines, paraffin was pumped into the chamber, V, in variable

charges down to about half load and then "cut out" altogether, the vapour valve, A, between the outer vaporising chamber and the extension c, of the combustion chamber being simultaneously put out of action.

A feature in the Barnes vaporiser, as used in the Ruston engines for running on paraffin (fig. 58), is the facility for heat-

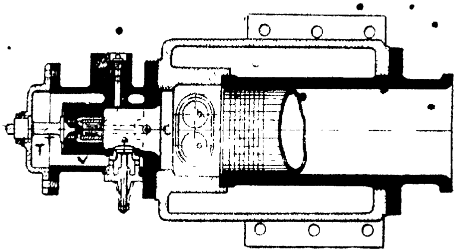


FIG. 57.—Sectional plan of Clayton-Shuttleworth paraffin vapour-feed vaporiser and automatic igniter.

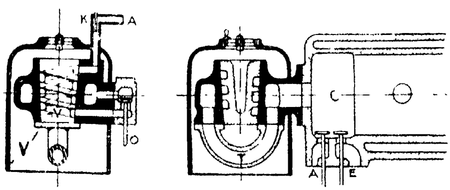


FIG. 58.—Sectional elevations of the Ruston paraffin vapour-feed vaporiser and automatic igniter.

ing the automatic igniter, T, at starting. Another feature is the grooved vaporising plug, V, located so as to be entirely surrounded by an annulus extension of the combustion chamber, C, the whole concern being easily detachable from the cylinder end. Oil is supplied in measured charges by a bucket device shown in fig. 59, designed to be operated by a cam and tappet on the full-charge or none system, which for simplicity is unequalled, further it cannot be meddled with, which is a good point under many circumstances. This device works in an overflow constant level over-cylinder cistern, T, to which paraffin is

supplied by a pump, from a tank within the engine base, in excess quantity by the pipe, I, the overflow returning through the pipe, O; the charge measuring bucket, B, slides over the feed tubes, V, the action of this is such that on the bucket being immersed it fills as shown, and on being raised by the gear, M, the charge runs down the feed tubes, V. Slightly varying charge feeds can be simply arranged for by slipping on a bucket of a greater or less capacity, thus the adjustment is definitely defined

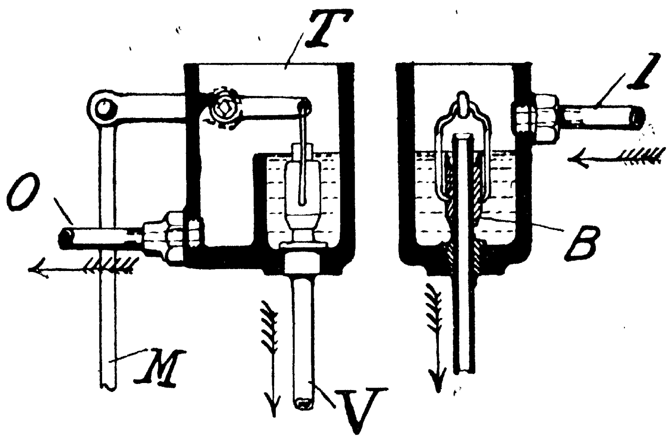


FIG. 59.—Feed measuring cup used on the Ruston paraffin oil engines.

for different grades of paraffin and cannot be tampered with. The pipe V (fig. 59) communicates with a snifting valve in the downtake extension to the vaporising groove, V (fig 58), a small volume of air entering at the open end, A, and the oil at K. There is a vapour valve, O, at the side to admit heated mixture from the groove chamber, V, to the combustion annulus leading to C; this valve and the feed bucket move in synchronism at every charging outstroke of the engine piston, both being cut out of action on the engine exceeding a predetermined speed.

Although a very different construction is followed in the Cundall vaporiser (fig. 60), the principle of feeding the paraffin in measured charges to an explosion-heated chamber, as at V,

is the same as in the foregoing. In this example paraffin is fed to a measuring device *via* the inlet, K, excess feed overflowing through the pipe shown: from this measuring cup the oil is drawn into the combined vaporiser and vapour-valve casing, V, and therein mixes with air drawn in at A, at each charging stroke following an exhaust stroke with the exhaust valve, E, held down on its seat, this valve is held open for a cycle at varying intervals on the engine exceeding the running speed required The advantage of this method, so frequently adopted in engines governed by cutting out the oil-feed charge, is that the temperature of the vaporiser and cylinder is thus maintained higher than when cold air is drawn in during non-explosive strokes There are two burners, L, for starting and running unloaded, but only one is necessary in ordinary working for the ignition

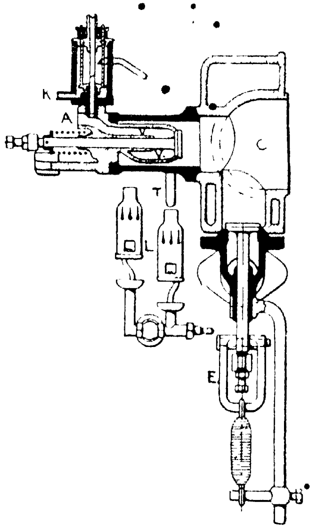


FIG. 60 —Vapour-feed vaporiser with tube igniter, used on Cundall paraffin oil engines.

The part flame-heated vaporiser shown in fig. 61 is similar to that used on a Fielding paraffin-oil engine which ran through the Cambridge R.A.S trials in 1894. This consists of a hot-air tube, H, a flame-heated vaporising tube, V, and a part flame- and part explosion-heated tubular chamber T, in open connection with the combustion chamber at C, and thus serves to ignite the charge.

Air to assist in volatilising the charge of oil fed in at O enters at A, the mixture, during a charging stroke, with the exhaust valve closed, is drawn from V, past the automatic vapour valve and through the tubular chamber, T, to the cylinder, when, on the return stroke, part of the mixture is compressed into T, and is thus ignited. In connection with a vaporiser of this simple

and easily detachable form, an automatic valve is used for the main air supply, and a governor-controlled tappet gear to throw out of action the feed pump when the exhaust valve is held open—*i.e.* during "cut-out" strokes.

The Watt vaporiser (fig. 62) may be said to be a development of the example shown in fig. 61, in that a volatilising supply of air at *a*, together with a pump-measured feed of paraffin oil entering by the pipe, *p*, after traversing a heated chamber, *c*, is drawn past a vapour valve *m*, to an extension *z* of the combustion chamber of the cylinder, *c*, but in this instance there is no lamp required after starting, excepting on continued runs on very light loads. To carry this into practical effect a large ignition chamber, *t*, is used connected by a small passage at the cylinder end of the extension, *z*, this to cause a portion of the compressed mixture, undiluted by the contents of the extension, *z*, to be forced into *t*, and to force the inert gas therein away from the communicating ignition port. To assist in the maintenance of a high temperature while running on reduced loads, a cowl, *x*, is used having flues, *f*, through which air can circulate when on full load to prevent overheating, and, of course, is thus made use of while the starting lamp is alight, but can be shut off to any required degree while on reduced loads, by the damper, *b*. In connection with this vaporiser the vapour valve, *m*, and feed pump are operated in synchronism to cut out the admission of firing charges when running below the rated load. Although the action of the exhaust valve is not under governor control, in ordinary working conditions, the vaporiser, igniter, and compression chamber are found to retain sufficient heat to compensate for the cooling effect of cold air drawn in through

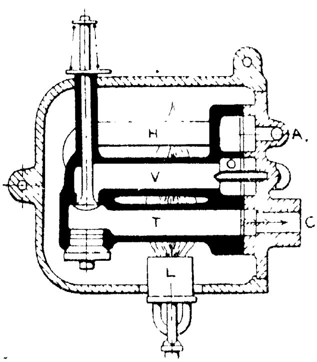


FIG. 61.—Flame- and explosion-heated vapour-feed vaporiser used on Fielding paraffin-oil engines.

the cylinder, under ordinary working conditions, provided that circulation through the cowl is stopped.

However, there are circumstances where the running con-

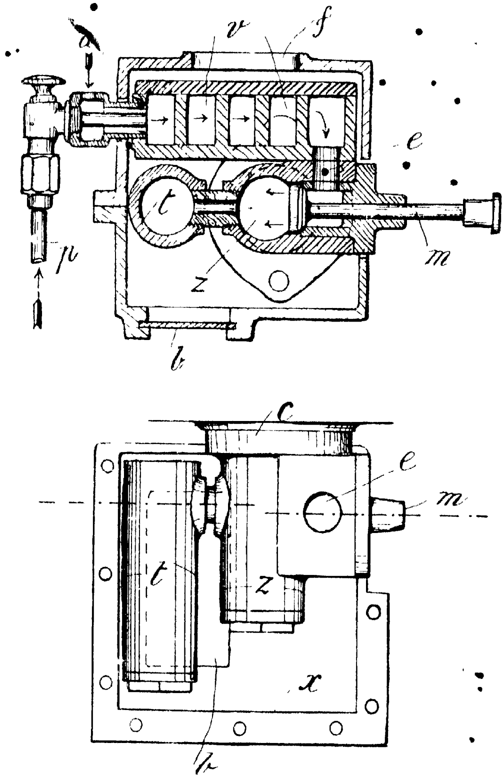


Fig. 62.—Watt vapour-feed paraffin vaporiser with automatic igniter.

ditions are so variable that an automatic igniter cannot be depended on to produce a clear exhaust on reduced loads; hence the number of vaporising systems in which an ignition lamp is retained under all running conditions. That shown in fig. 63

is one of them. here a very similar combination of vaporising chamber, V^1, vapour valve, V, and bulb-end extension, V^2, with pump-measured feed injection, as at K, is used. The difference consists mainly in the disposition of the component parts—e.g., the paraffin feed is sprayed in past an atomiser nozzle through a Venturi tube, M (as in a petrol carburettor), to the lamp-heated chamber, whence the mixture is drawn through a form of bulb-vaporiser cylinder extension, which would seem to be a very practical method, especially for small engines, as the design lends itself to considerable latitude in the timing of the ignition.

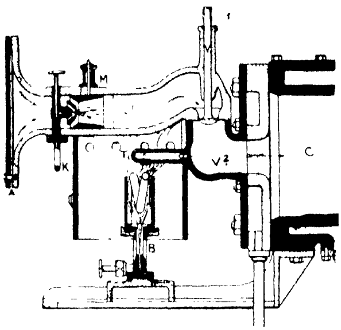


FIG. 63 – Robey Sauner vapour-feed paraffin vaporiser with flame heated igniter

Another variant under this class is the Nicholson vaporiser (fig. 64), used in the Britannia paraffin-oil engines of comparatively small power. In this example there is no feed pump, suction being depended upon to draw the oil—from a tank contained in the base of the engine—past a check valve to the heated space, A, and thence past an automatic vapour valve to another heated extension chamber open to the cylinder. An automatic igniter, B, consisting of a jacketed tubular passage open at each end, to passages leading to the compression space, is located under the vaporiser, and thus immediately over the starting lamp, the whole affair being neatly covered in by a cowl harmonising with the cylinder. The exhaust valve is actuated by a trip gear, and as the main air inlet valve, C, is automatic, the cylinder and vaporiser extension are not in consequence of this exposed to the cooling effect of cold air during "cut-out" charging strokes. The funnel, E, is for the purpose of filling the feed pipe before pulling round the wheel at starting.

The Blackstone paraffin-oil engine works on the induced

jet principle, in combination with the "all-or-none" charge method of governing, as used in each of the foregoing examples included under this class; but, as shown in fig. 65, there are some important differences to the usual practice followed in

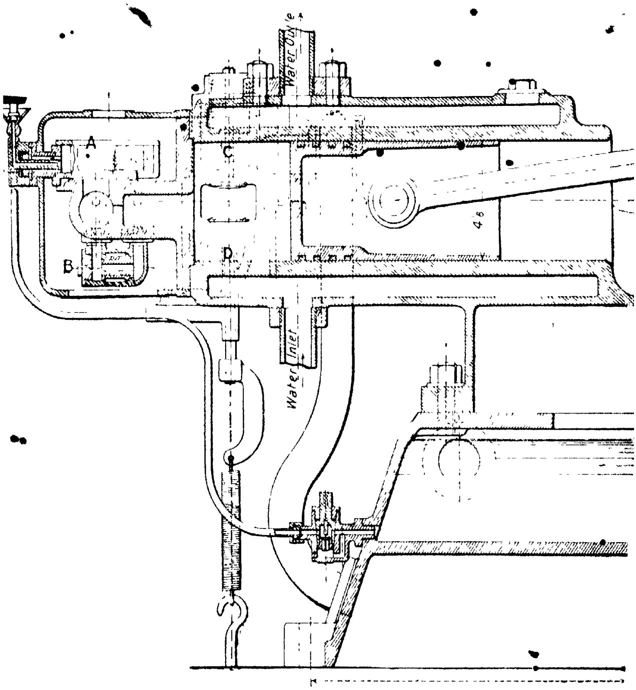


FIG. 64.—Nicholson vapour-feed vaporiser with automatic igniter, used on the Britannia paraffin-oil engines.

engines of the vapour-feed class. For instance, in place of tappet-trip gears on either the feed pump, the vapour valve, or the exhaust valve, or any two of them together, a governor-controlled cam-actuated plug, *g*, is arranged to shut off communication between the internal vaporiser or cylinder extension, *b*, when the speed exceeds normal, the plug remaining closed, thus

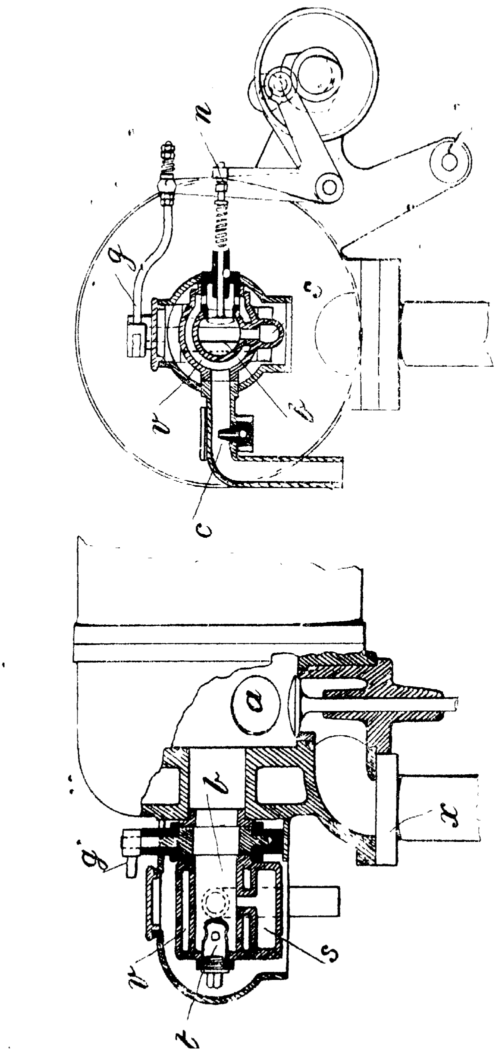


FIG. 65.—Vapour-feed vaporiser with automatic igniter, used in the Blackstone oil engine for paraffin.

preventing air from being drawn across the nozzle, e; hence no charge is then admitted during the following admission stroke, only air through the automatic valve in communication with the port, a. The *modus operandi*, when working fully loaded, is for a jet to be induced through the nozzle, e, by the auxiliary air supply through the pipe shown, the vapour valve, h, being then open, as always during the admission strokes, thus opening free communication with the cylinder, through the interior vaporiser extension b: then, during the following instroke, a portion of the charge is compressed into this chamber and towards the end of the stroke is ignited by the insulated cap, t. To facilitate starting an extension s, is provided, which is always in communication with e, through a small central passage. This lower chamber is situated just over the blow-flame, and can thus be heated in about ten to fifteen minutes to such intensity as to fire the charge on pulling round the wheel. The lamp is then left alight until the engine has been running on the load for five to ten minutes or so, when the flame can be extinguished and the cowl closed by the cover, as shown. The feed nozzle is fed from a small overflow cistern adjoining, wherein the level is maintained by a pump drawing from a tank within the base of the engine to just below the apex of the nozzle.

More than ordinary interest attaches to the Melhuish vaporiser (figs. 66 and 67), in so much that in this the vapour-feed principle is shown applied to an engine operating on the two-stroke cycle: further, in order to avoid circulation of vaporised mixture through the transfer pump, the engine is designed for the mixture to be drawn into the explosion cylinder direct by vacuum effect due to displacement in an annulus caused by the outstroke of an enlarged extension of the piston. Thus at the end of the outstroke the contents of the explosion cylinder first exhaust through a port uncovered by the power piston into the annulus behind the pump piston, thus causing a fresh charge to be drawn into the explosion cylinder *via* the non-return valve shown. On the return stroke this charge is compressed and ignited by the flame-heated tube, and simultaneously the inert gas contents of the pump annulus is exhausted through a spring-loaded non-return valve, which, wnen the engine speed exceeds

normal, is held closed by a governor-controlled trip gear, thus preventing a fresh charge being drawn in at the end of the succeeding outstroke. The vaporiser consists of a pot open at the top and having around its base an annulus open to the combustion chamber. There are two tubes leading down to near

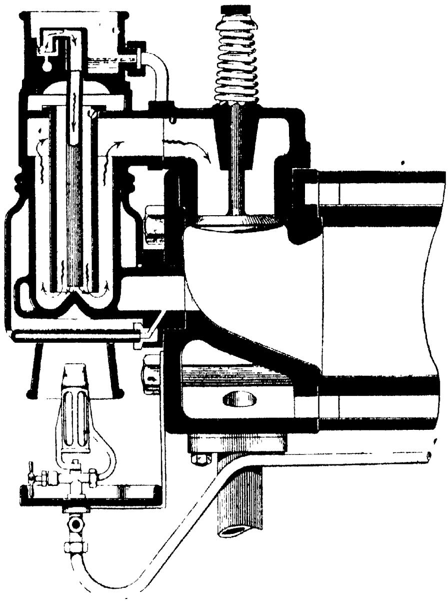


FIG. 6 : Melhuish vapour-feed vaporiser with flame heated igniter, used on the Gothic paraffin oil engine.

the bottom of the heated pot, the outer one for the main air supply drawn from the base of the engine, as indicated by the arrows, and the inner pipe for the spray charge and atomising air, the oil (paraffin) being drawn from an overflow cistern supplied from a pressure tank, which also feeds the burner.

Injection-feed Vaporisers.—*Class 4.*—As explained in this chapter, the development of internal combustion engines capable of working on flash-proof lamp oils has for the most part been

extended in four directions, each starting at about the same time—*i.e.*, within the period 1885–1890. Of these, the Humes-Priestman exhaust-heated vaporiser engine with compressed-air atomiser and electric ignition, as used on the Etève mineral-spirit engine, was first patented in 1885 (8411); then followed

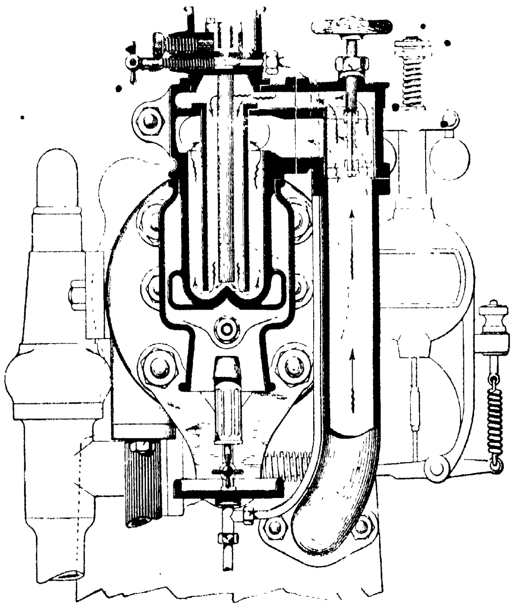


FIG. 67.—End section of Melhuish vaporiser, showing oil and air regulators.

the pump-feed injection exhaust-heated vaporiser of Smyer's, also patented in 1885 (11290); then the combined pump-drip-feed vapour-jacketed extension of the combustion-chamber vaporiser, first patented by J. H. Knight (2783) in 1887; then the induction spray-feed exhaust-jacketed vaporiser with automatic mixture control, first patented (6990) in 1890 by the writer, this being the class of paraffin-oil vaporiser now so extensively adopted in all the numerous high-speed petrol-paraffin

motors for small marine craft, field tractors, commercial road cars and stationary work of many kinds. Then followed Akroyd Stuart's automatic ignition pump-injection engine, with the vaporiser separated from the cylinder end by a constricted passage, patented in 1890 (15994). This inventor, after experimenting with flame- and conduction-heated vaporisers, was convinced that this was the most practical method of vaporising paraffin oil for stationary engines, in which it was desirable to be able to dispense with a burner other than for starting, and his conclusion that this was the only way has since been to a very considerable extent verified, for instance, his engine, entered by Hornsby Brothers of Grantham, was awarded the first prize at the R A S. trials in 1894 A very noticeable feature in all engines of his original design is their remarkable smoothness of running and adaptability for variable loads without a trip-gear for the exhaust valve, as found necessary in so many engines when running on light load without a lamp, another feature is their freedom from that harsh explosion effect so commonly associated with all engines in which the paraffin oil is vaporised before being drawn into the cylinder. The method adopted in the Hornsby-Akroyd engines is to inject a variable feed direct into a ribbed vaporiser constituting a considerable proportion of the compression space, this chamber being connected to the cylinder by a neck, partly to avoid premature ignition, partly to prevent the vapour from being drawn into the cylinder, and partly to insulate the vaporiser from the water-cooled cylinder end. An important feature in engines of this design is the correct proportioning of the vaporiser capacity to that of the piston displacement and to the size of cylinder, the larger the cylinder the less the proportionate size of the

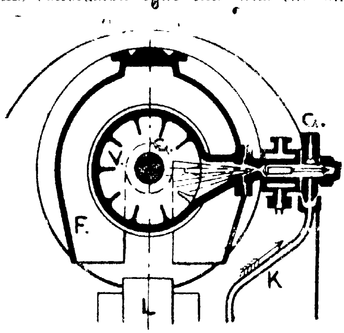


FIG 68 —Cross-section of Hornsby-Akroyd injection vaporiser

vaporiser, another factor of importance is the correct compression for the different brands of oil used; another, the temperature of the vaporiser, which in small engines can be regulated by a cowl, and in those of larger sizes by jacketing a part of the neck next the cylinder end. The feed is injected into a cone-shaped projection at the side of the vaporiser, as shown in

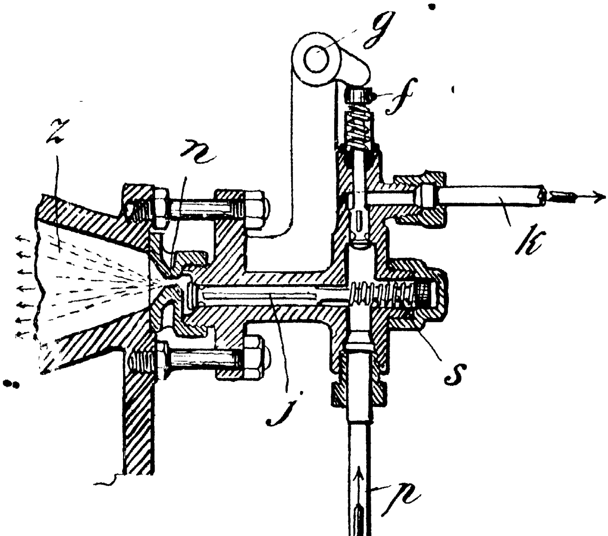


FIG. 68A. Spray-injection nozzle and governor-feed valve for Hornsby-Akroyd paraffin-oil engine.

figs. 68 and 68A. In the cross-section, the ribbed chamber, V, connected to the cylinder by a neck, G, is as shown surrounded by a large cowl, F, to accommodate the application of a large fan blow-lamp, L, for starting. Details of the injection valve are shown in fig. 68A. Here, p is the feed pipe from an adjustable stroke cam-actuated pump, which forces the charge of oil as spray into the diffusing cone, z, past a spring-loaded check valve, j, and nozzle, n, which it is important to keep clean The speed of the engine is regulated by a bye-pass valve, f, under the control of a

fly-ball governor and tappet, *g*. Thus there are no complete cut-out charge strokes, the force of the explosions being varied in proportion to the charge admission, excess oil returning through the pipe, *k*, to the supply tank. The injection is timed to take place somewhat later than the air intake, the valve for which, together with that for the exhaust, is situated at one side of the cylinder, so that neither the diffused spray nor vapour mixes with the ingoing air, as in vapour-mixture vaporisers. The charge is therefore unequally mixed, and forms a richer mixture in the vaporiser than in the compression space next the piston.

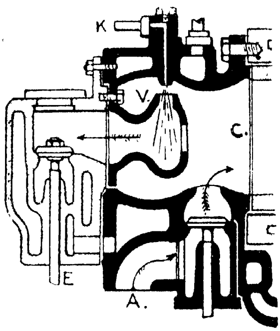


FIG 69.—Norris-Robey explosion-chamber vaporiser, with injection feed.

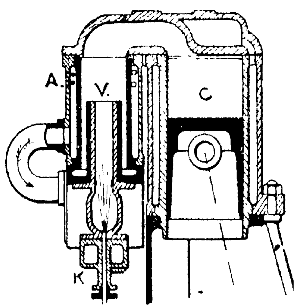


FIG 70.—Gibbons explosion-chamber vaporiser, with injection feed.

thus causing certain ignition with weak mixtures, as well as slower combustion than in vaporiser systems in which all the heated mixture is drawn into the cylinder.

An interesting variant coming under the injection class is shown in fig. 69. The purpose in this, the Norris vaporiser, was to avoid any possibility of the chamber, V, from bursting, and for that reason this is not subjected to pressure. As in the preceding example, the ignition shell is not exposed to the cooling effect of the ingoing air at A, and is so arranged that all the exhaust passes through it to the valve, E. The oil feed is injected at K in variable volume, past a spraying nozzle at the side of the combustion chamber, C, and is thence projected into the combined vaporising and ignition shell, V, at considerable

velocity by a variable-throw pump. Engines on the Norris system were exhibited at several of the R.A.S. and other shows.

The sectional plan (fig. 70) represents another variant of this class. This, the Gibbons vaporising system, departs somewhat from the simple design the direct injection lends itself to, so much that an insulated tube projects within an extension of the explosion or combustion chamber, V, continued around to one side of the cylinder, C, this extension is jacketed by an air chamber, and the air entering at A is drawn into the cylinder past a piston valve in the casing below. Vaporisation is carried to a degree in excess of that necessary for paraffin oil, whatever

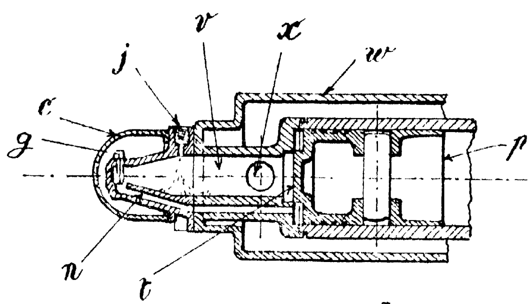


FIG. 71.—Vaporiser used in National paraffin-oil engines, showing timing device.

the brand used; the spray feed injected from the nozzle at K, along the ignition tube, first impinges on to the unjacketed cover and then mixes with hot air, when the mixture is compressed into the vaporiser ignition chamber. Although not commending itself by reason of the considerable radiating surface surrounding the combustible, an engine on this system exhibited at the 1895 R.A.S., held at Darlington, appeared to run smoothly unloaded.

A more recent development of the direct injection method is shown in fig. 71, in which the principal feature is the method adopted for the automatic timing of the ignition. This is effected by a projection, *t*, on the end of the piston, *p*, which during the last 15° or so of the compression stroke super-compresses a portion of the combustible along the channel, *n*, and up past

the igniter-plug, *g*. In accordance with this design, used in the National paraffin-oil engines, the charge being injected at *j*, far behind the admission and exhaust zone at *x*, will cause the mixture in the vaporiser to be much richer than at the front end,—so much so, in fact, as to be non-explosive until near the completion of the stroke, when weak mixture is forced along *n*, so diluting the combustible. The strong point of this vaporiser is that change of load and charge volume does not materially affect the timing of the ignition.

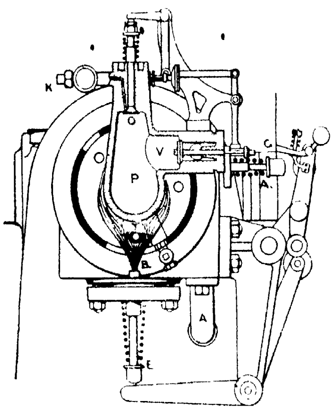


FIG. 72.—Cross-section of injection vaporiser used in the Globe paraffin-oil engines.

In the vaporising system used on the Globe[1] engines, several of which the writer has seen at work under different conditions, there is no feed pump, the charge being drawn past a gravity-fed snifting valve, O (fig. 72), supplied at K, from an over-cylinder tank. The charge is controlled by a tumbler governor, G, which simultaneously cuts out the auxiliary air valve, V; the same cam lever also operates the main air valve, A The vaporiser, P, is in the form of an upturned bend unjacketed extension of the cylinder compression space, underneath is an ignition tube, T, but it is only required at starting and for light loads. As in all vaporisers with an automatic snifting or induction feed, the spray is drawn, together with a part only or the whole of the air supply, through the vaporiser (which may be entirely explosion heated or part lamp-heated) and thence into the cylinder, the mixture is then homogeneous throughout, and on ignition explodes more violently than in an engine having a pump-injected feed independent of the air supply, notwithstanding that with an injection feed the spray is raised to a

[1] Made by Pollock, Whyte & Waddell, Glasgow.

higher temperature. The two feed systems also involve two distinctly different governing methods, pump injection working better with a "variable feed," and suction injection better with a "cut-out" feed, thus in all engines (class 4) in which the fuel and air are drawn in together through the vaporiser, the exhaust valve is held open at intervals when working at less than full load, in order to obtain regularly timed ignition. In the Globe vaporising system just described, only sufficient air is drawn through the bend extension to assist in complete vaporisation at a lower temperature, and in this exception to the ruling practice, only the supplementary air supply and not the main supply is cut out. The advantage of this method is obvious, as a greater weight of air can be drawn in direct to the cylinder than through the hot vaporiser. The Capitain engine (fig 73) presents another example in which this method is adopted, but in modified form Here, the supplementary air supply at A is admitted by an auxiliary automatic valve at the end of a tubular combined vaporiser and ignition tube, V, the charge of paraffin oil being injected by a feed pump through the duct, O. In this, the main air supply is drawn in past the valve, A, direct to the cylinder, excepting during "cut-out" strokes, when the exhaust valve is held open and the pump out of action. The burner, L, is kept alight continuously, and the cone-shaped combustion chamber, C, unjacketed. Thus for the smaller sizes this engine, which is of the short-stroke high-speed enclosed crank type, not only works well but occupies comparatively little space.

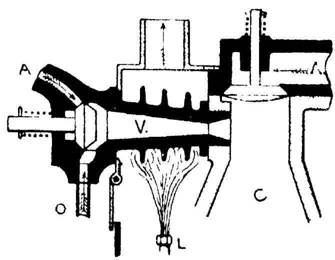


FIG 73 Combined vaporiser and igniter used in the Capitaine paraffin-oil engines

The Campbell vaporiser is better adapted for horizontal engines, and as shown in fig. 74, for the smaller sizes to run on paraffin oil is fitted with an ignition tube, T, and a comparatively small vaporiser, V, through which the total supply of air from A is drawn past a combined air and oil feed automatic valve, the

paraffin being supplied from an over-cylinder tank to the pipe, O. This vaporiser, which is totally covered by the burner chimney, is connected to the side or end of the combustion chamber by a passage, C, located about half-way down; thus the charge of vapour and air does not become so dilated as it would if connected at the tube zone. However, as designed for engines of larger size, with automatic igniter (fig. 75), the vaporiser, *v*, is connected to the cylinder end by a bend at the base, with the automatic fuel and air valve, *a*, at the top. Although classed under paraffin vaporisers, semi-refined or intermediate oils, such as gas oil, can be used with this form of vaporiser in engines of the larger sizes. The automatic igniter consists of a plug, *g*, having two ducts, one extending downwards to an elongated cell, and the other closed at the bottom; the temperature of the plug can be regulated by a sliding cover, *b*, which, at starting with the burner alight, is taken off. There is a cap at the base of the plug to facilitate cleaning, which is a point of some importance in running on the heavier oils. In all vaporiser engines, excepting those of small size, there is a tendency for the heated mixture to explode violently when under full load, thus causing more or less pounding according to design of vaporiser, brand of oil used, and, of course, size of cylinder and degree of compression. To suppress this, either the exhaust valve may be set to close early, or a bye-pass fitted between the air and exhaust pipes; or again, and the most usual practice, a drip or injection water feed can be fitted to the cylinder as shown at *w*, in fig. 75, or to the vaporiser as shown at *w*, in fig. 77; but in either case is only required when running at or above three-fourths the rated load.

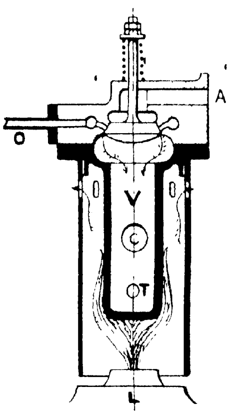


FIG. 71.—Campbell paraffin oil vaporiser with shifting feed injection and lamp-heated igniter.

The vaporiser used in the Tangye engines is more of a

globular form, as shown in figs. 76 and 77; otherwise, excepting in minor details, does not materially differ from those just described. In this the air admission and oil feed are controlled by the automatic valve, *a*, on the globular extension, *v*, with the ignition tube arranged either at the end, as in fig. 76, for the smaller sizes, or below for larger engines, wherewith the burner is not required after starting so long as a continuous load does not fall much below one-half the power of the engine. The oil feed to apertures on the air-valve seat is connected to a cistern maintained at constant level by a pump. The Smith-Dudbridge vaporiser shown in fig. 78 is of the same type, but smaller; a drip feed is used and regulated automatically by the opening of the air-admission valve, *a*. Paraffin oil is supplied from a cistern (fig. 79) to a regulator valve, *p*, controlling the rate of feed to an aperture, *z*, leading

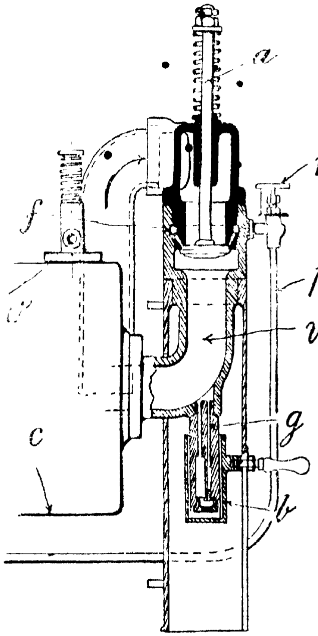


FIG. 75. Campbell vaporiser and automatic igniter.

to the air-valve seat, as shown in figs. 74 to 77, but in this instance the oil level in the feed cistern can be adjusted by a shell-plug, *r*, by means of a curved overflow groove, *w*, to the return outlet, *p*, leading down to the main tank, the exact level being indicated by a pointer and indexed dial, *x*. Paraffin oil is supplied, as shown in fig. 52, by a pump up the geyser inlet, *f*, to the plug well, whence it is drawn *via* the flanged connection, *v*, to the feed regulator, *p*. The vaporiser is encased by a close-

fitting cowl having a flue-door just below the ignition tube, *t*, used to start on and for continuous running on light loads. On ordinary working loads the lamp is unnecessary, the ignition then being effected by the hollow star plug, *g*. As in engines with unjacketed pump- and suction-injection vaporisers, shown in figs 73 to 79, the speed of the engine is controlled by holding open the exhaust valve by an automatic trip gear on the cam lever operated by an inertia governor

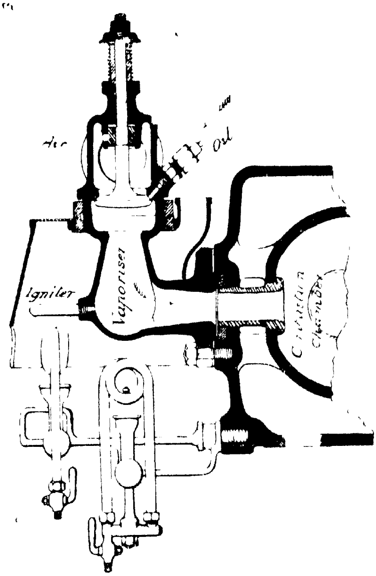


FIG. 76.—Tangye starting feed bulb vaporiser, showing starting and ignition lamps

A very simple form of vaporiser with direct pump injection suffices for two-stroke engines of the piston-controlled air-admission and exhaust type as, for example, shown in figs. 80 and 81: such engines may either have an enlarged piston extension to the power piston, or an enclosed crank chamber (these two methods being most generally used in all engines of this type) to serve the purpose of an air pump to displace the exhaust contents by an air charge immediately after the pressure in the power cylinder has fallen to below that in the "intermediate transfer chamber," which with annular displacement as shown in the horizontal engine is the chamber below the outlet valve, *a*, and in vertical engines is the crank chamber There are no valves subjected to pressure, nor indeed any at all, with a design as shown in fig 81 However, engines of this type have their faults, the worst of which is a limitation to range of speed

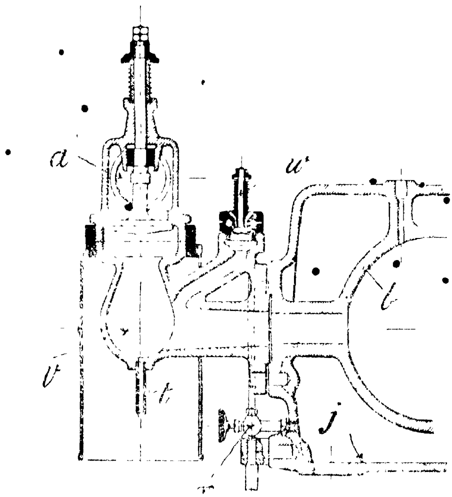


FIG. 77.—Vaporiser of Tangye oil engine with water injection.

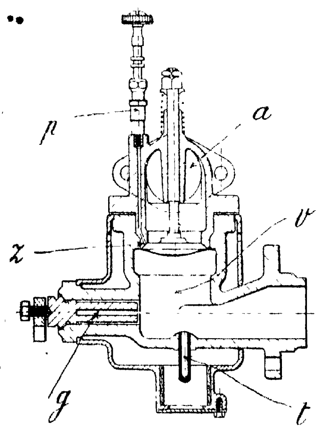


FIG. 78. Lampless vaporiser used in Dudbridge oil engine below 40 b.h.p.

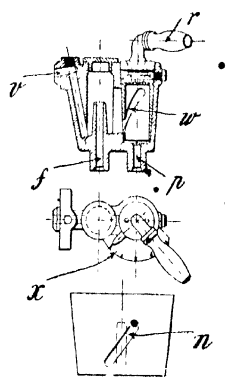


FIG. 79.—Oil-measuring valve used in the Dudbridge lamp-heated vaporiser for paraffin.

control, as, when run beyond the designed speed, a considerable volume of exhaust products is then pent up in the cylinder, thus

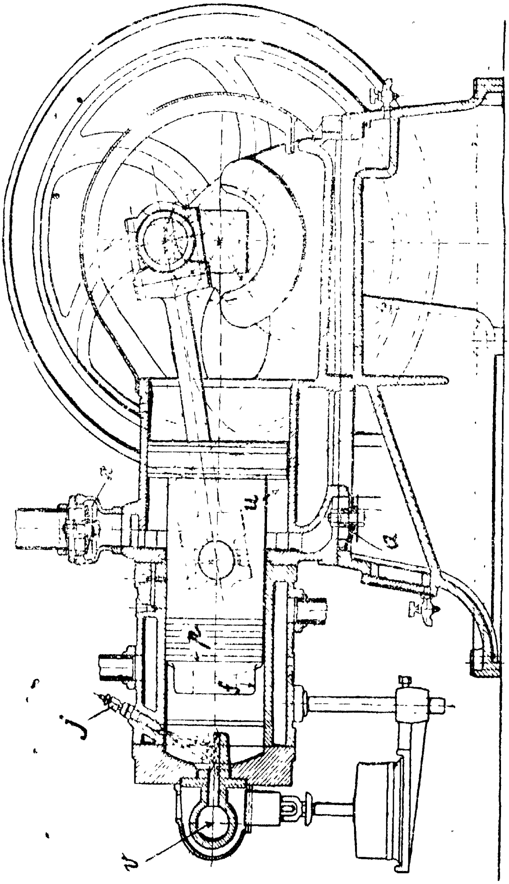


FIG. 80.—Sectional elevation of Munktell two-stroke paraffin engine. (Differential piston type.)

reducing the power efficiency; another is the insufficiency in capacity of the air pump to get the most out of the engine

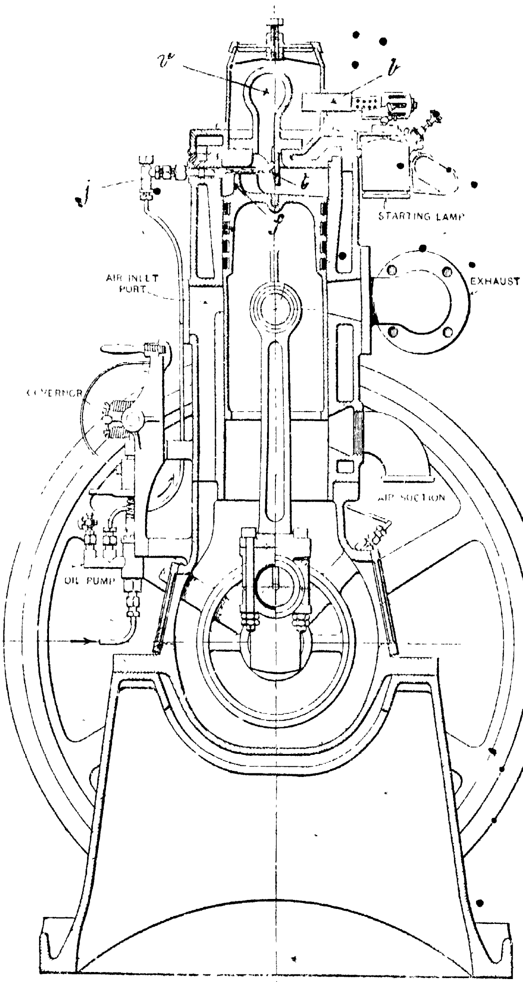


FIG. 81.—Sectional elevation of Mietz and Weiss two stroke paraffin engine (Enclosed crank-chamber type.)

excepting at low speed, owing to excessive clearance. In other respects these two-stroke designs are unique in their simplicity, requiring neither side-shaft nor valves. The most successful form of vaporiser is the globular or hot bulb, which for paraffin oil may be likened to a bulb-end ignition tube, the spray-injection pump can be operated direct from the crank shaft, and the rate of feed be governed on the "all-or-none" or variable system; the method giving the best results, however, is to combine the two, using the "cut-out" below half power. For small paraffin engines it suffices to spray the charge on to a deflector as at t, from a simple form of nozzle as at y, this usually having a check valve, although not absolutely necessary unless at considerable distance from the injection pump.

CHAPTER VI.

INJECTION VAPORISERS AND ATOMISERS USED IN ENGINES CAPABLE OF RUNNING ON SEMI-REFINED, CRUDE, AND RESIDUAL OILS.

THE first instance on record of liquid fuel being used in an internal combustion engine is that of Street's gas pump of 1794; in this engine vegetable, animal, or mineral oil was poured in measured charges into the lower end of a vertical cylinder supported and partly surrounded by a furnace when the piston —connected by a beam to the pump plunger—was near the bottom of its stroke, a cock on the feed pipe was then closed, and air forced in by a hand pump until the mixture exploded. This process, even in comparison with a Newcomen steam pump, was necessarily slow, but in the light of present developments none the less interesting. Hargreave's slow-combustion engine is a direct development of the Street engine, and, judging from one shown in London in 1888, worked with an economy unsurpassed by any engine of to-day, considering the nature of the fuel used. This was a two-stroke pressure-air admission fuel-injection engine, but worked with a very low range of pressure which was fatal to its making the headway expected in the face of improvements in steam, gas, and oil engines following soon after. However, the purpose here is the consideration of the different methods used in more self-contained and higher-pressure engines capable of running on heavy residual oils. Of these there are four classes: (1) the carburettor class, limited to the more volatile liquid hydrocarbons, (2) the vapour-feed vaporiser class, for use with refined and semi-refined flash-proof oils; (3) the injection-vaporiser

class, and (4) the injection-atomiser class. Engines having an unjacketed vaporiser with injection feed, excepting those of the smaller sizes, are generally adapted for running on semi-refined oils, and in the larger sizes on crude and residual oils, which latter remark also applies to compressed air and mechanical atomiser engines of the high-compression slow-combustion class, which, being entirely independent of a vaporiser and capable of starting cold, are alone suitable for engines of really large power.

Injection-feed Vaporisers adapted to Four-stroke Engines. —The first to use an unjacketed vaporiser with a direct pump injection feed was Akroyd Stuart, who, after several experiments with different types of pump- and drip-feed vapour-jacketed and flame-heated vaporisers, arrived at the conclusion that for flash-proof lamp oils an engine should be independent of a lamp after being started; with this purpose in view, he conceived the idea of a separate unjacketed vaporiser combustion chamber connected to the cylinder by a short restricted passage, this to separate the vapour, generated during the injection of the charge, from mixing with the ingoing air to the cylinder; also to allow the vaporiser to attain to a higher temperature. By this construction premature ignition was prevented, and by suitably arranged ribs, vaporiser capacity, and compression, he was enabled to obtain reliable and regularly timed ignition under ordinary fluctuating load conditions. This was in 1890, his two patents, 7146 and 15994, of that year being then acquired under licence by Hornsby's of Grantham, who have since then made many improvements on the engine, but without radically departing from the original design of vaporiser. Stuart appears to have first tried an unjacketed vaporiser extension to the cylinder, of smaller diameter and without a restricted connecting passage; this had an automatic valve at the end for the air admission and the injection nozzle on one side, and was included in his 1890 patent (7146), this, however, he decided to abandon, owing to trouble with premature ignition, the compression not being continued high enough for the injection to be delayed till the completion, or nearly so, of the compression stroke, as now practised in larger engines of improved design. His original design is interesting, however, in being the first, suitably modified

for a higher compression, in which ignition could be timed by the injection, and although not then appreciated as of any particular value for paraffin, the advantage of a bonnet, dome, bulb, or pear-shaped form of unjacketed vaporiser, with direct injection spray feed, is now well recognised and accepted as the standard design for all lamp-started two- and four-stroke engines for running on the cheaper residual oils.

A cross-section of the Hornsby-Akroyd bottle-neck vaporiser is shown in fig 82, here will be seen the relative diameters of the vaporiser, contracted neck and cylinder, indicated at *v*, *t*, and

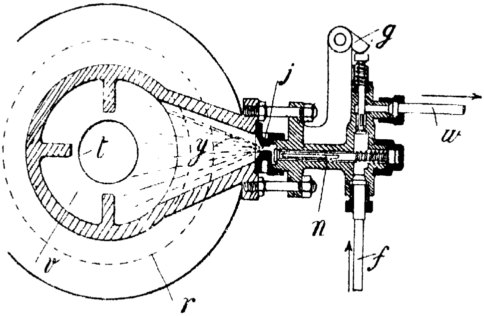


FIG. 82 Cross section of vaporiser used in the Hornsby-Akroyd residual-oil engine, showing details of the injection feed.

r; about midway along one side there is a diffusion chamber, *y*, on to which is clamped the nozzle, *j*, this being screwed on to the injection valve casing, containing a check valve, *n*, and governor control, *g*, to the bye-pass valve; the pump is cam driven at constant stroke, excepting for hand regulation, and forces a full charge through the pipe, *f*, during the compression stroke, surplus feed returning to the main tank *via* the overflow, *w*, according to the load on the engine. In earlier engines the charge used to be injected during the air-admission stroke, thus allowing more time for vaporisation, which is an advantage in very small engines, but now with higher compressions the injection is delayed until the end of the admission stroke, and in engines of larger sizes until nearly the end of the compression

stroke. But to reduce the angular period of the injection presents some difficulty in four-stroke engines, owing to the motion depending on the half-speed shaft, and to get over this the plunger is heavily loaded by a spring and operated by a cam with a sharp release, the charge is thus forced into the vaporiser at great velocity, and, whatever its viscosity, broken up into minute particles.

A similar effect is produced in the Ruston injection-timed ignition engine, details of the vaporiser, atomiser, and force pump of which are shown in figs. 83 and 84. Here oil drawn into the pump *via* the pipe, *p*, on the outstroke of the plunger, *e*, is quickly forced past a check valve and through the delivery pipe, *f*, to the atomiser at the moment the cam, *m*, passes the roller of the pump lever, *k*. The atomiser consists of a two-diameter plunger valve, *j*, which is raised against the resistance of a stiff spring during the injection period, the oil then being forced into the pear-shaped vaporiser, *i*, in the consistency of a fine mist, *g*, and against the full force of a very high compression of from 250 to 270 lbs per sq in., the lift of the injection valve is limited by a stop to 0·03-in., and the period of the injection to from 30° to 40°, commencing about 10° or so before the termination of the compression stroke. Leakage of pressure oil past the piston, *j*, of the injection valve returns to the bye-pass chamber of the pump *via* the pipe, *w* and thence to the tank by the pipe *t*. A charge is delivered at the end of each compression stroke, the quantity being determined by the bye-pass valve, *q*, which is raised to a variable extent by the governor, through the rod, *y*, cam, *c*, and pivoted lever, *r*; the fulcrum of this, consisting of the pointed end of the set-screw, *s*, is adjustable. In order to obviate any tendency for harsh impact between the cam and plunger, a fibre buffer, *x*, is inserted in the end of the plunger, thus preventing metallic contact between the plunger and the cam-lever screw, *i*. The fuel-injection valve casing is jacketed sufficiently, as at *l*, to prevent overheating, by water circulating through this from the cylinder jacket to the water-injection air-snifting valve, *h*, at the end of the vaporiser. The water feed found in most vaporiser engines is necessary to suppress a tendency to thump under heavy loads, which varies according to the nature of the

oil used, more water being required for crude oil than for residual oil. In this engine a very high compression is used and a small vaporiser. For instance, on Java crude oil a 40-b.h.p. engine on extended test shows a maximum consumption of 0·56 lb. per b.h.p.hr. at full load and 0·71 lb. at half load, the

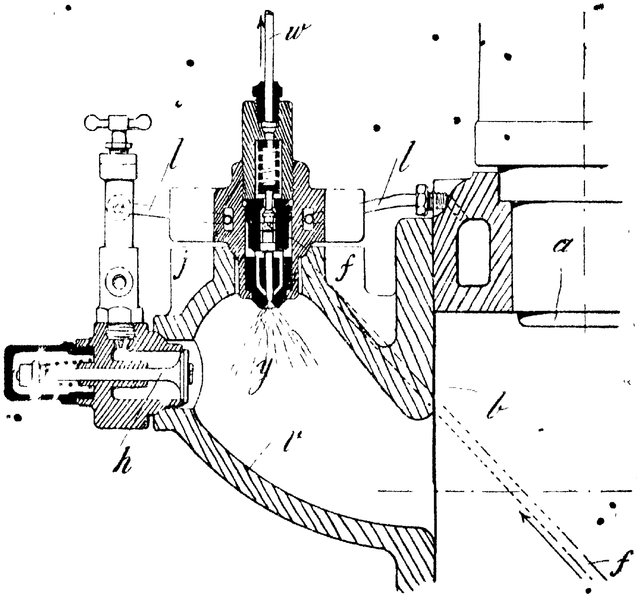


FIG. 83.—Sectional elevation of vaporiser used on the Ruston residual-oil engine, showing details of the mechanical atomiser.

compression being 270 lbs. and maximum explosion pressure 400 per sq. in.

In another test with a Ruston atomiser engine on Russian crude oil (running on a 52-b.h.p. load) the consumption per b.h.p.hr. was 0·45 lb., and on residual or fuel oil 50·5 b.h.p. was developed on a consumption of 0·48 lb. per hour. The useful pressure on the piston during the full-load tests on residual oil averaged 80 lbs., and 46 lbs. on the half-load, which shows an efficiency of over 30 per cent. of latent energy converted into useful work.

The injection vaporiser principle has been taken up to a surprising extent on the Continent, but principally as applied to

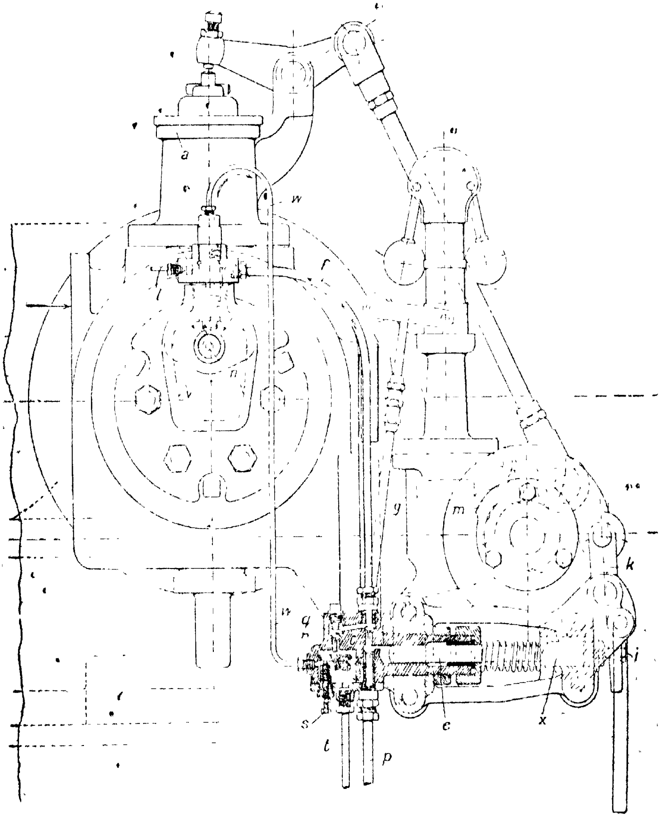


FIG 84.—Pressure-jet atomiser and injection pump used in the Ruston crude-oil engine.

engines of the two-stroke type with enclosed crank chamber. A representative design of vaporiser with pump-injection feed is shown in fig. 85, applied to a twin-cylinder four-stroke

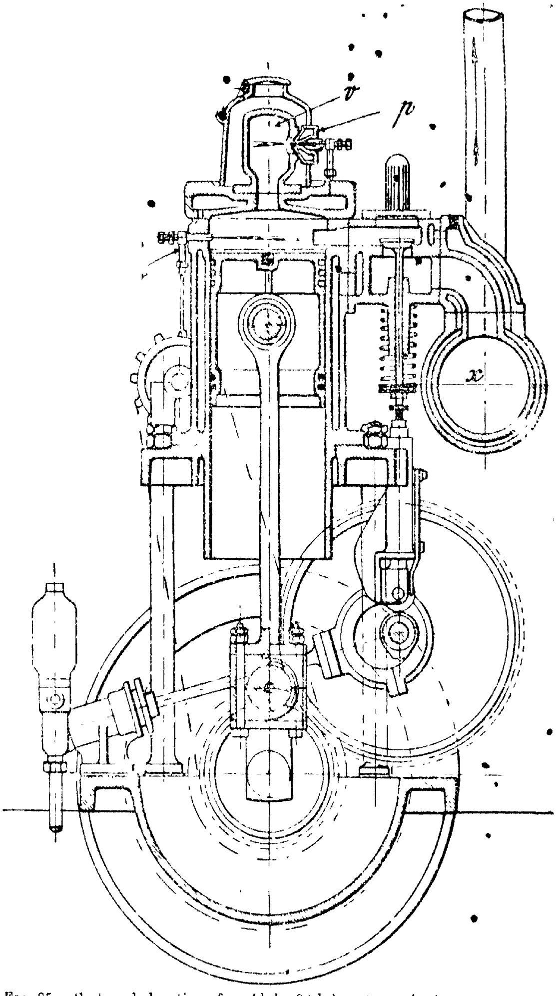


FIG. 85.—Sectional elevation of an Alpha 33 b h p. two cylinder marine engine showing vaporiser and injection nozzles for fuel and water.

marine engine of small size. This, known as the Alpha, and of Danish make, is a typical launch engine capable of running on semi-refined and any grade of flash-proof lamp oil, the cylinders are 7·5-in diam. × 10·5-in stroke, and the rated power 33 b.h.p. The design is light, and of the open-build entablature form, with absolutely no embellishment. The vaporiser, *v*, of restricted passage design, is bolted to a water-jacketed cylinder cover and provided with a close-fitting cowl having two hinged doors used for starting with a blow-flame, and afterwards for regulating the temperature of the vaporiser. The injection nozzle, *p*, is water-jacketed and bolted on to the side, the charge is forced past a simple form of spring-held check valve and thence through a plain jet aperture, which remark also applies to the water-injection nozzle, *w*, whence a spray is projected across the combustion chamber and so into the admission and exhaust pocket, and is timed to function during the exhaust stroke.

A somewhat heavier duty engine is the Hein, also a Danish make, illustrated in fig 86, and designed for trawlers and other marine craft, it is arranged with the admission and exhaust valves as well as the vaporiser on the cylinder head. The vaporiser, *v*, practically constitutes the combustion chamber, and is separated from the cylinder, *c*, by a long neck. The injection-nozzle casing, *j*, bolted on to the side, is not water-cooled, the charge is projected on to the opposite side of the vaporiser, which is slightly inclined to project the contents during expansion away from the cylinder wall. Ignition is timed by compression, vaporiser capacity, and length of neck, the charge is injected during the compression stroke. The Hein engines, which can be run on semi-refined or residual oils, are very substantially built.

The Crossley residual oil engine for medium powers, see figs. 87 and 88, is constructed more on the lines of the original Akroyd design with dividing neck, in that the vaporiser, *v*, is connected to the valve chamber of the working cylinder by a restricted passage, *tt*, but is smaller, of spheroidal form, and works with a higher compression. The fuel-injection atomiser is fitted with a spray nozzle, *j*, having a series of diagonally disposed orifices devised so as to project the spray in conoidal form against the heated curved wall opposite. Only the outer half of the vaporiser is unjacketed, the line of the dividing joint

being determined by the size of engine, there are no ribs or other internal projections excepting the ignition detachable thimble, *i*, at the bottom outer end. The fuel—which in quite small engines is paraffin, but which in engines over 20 b.h.p. may be semi-refined oil, and in sizes over 40 or 50 b.h.p. residual oil—is regulated by a variable stroke pump, which is governor-controlled on the stepped-die principle, the governor also brings

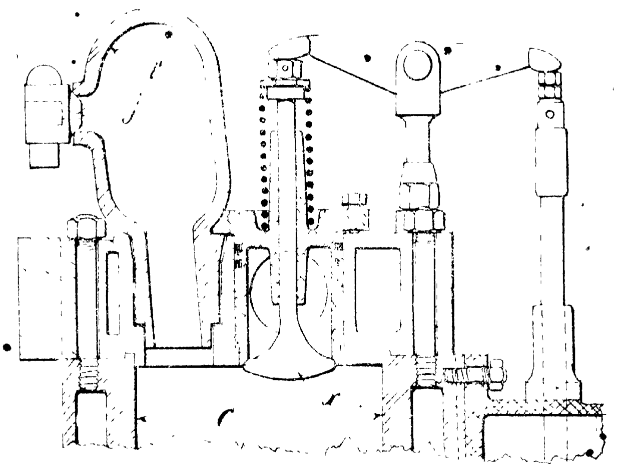


FIG. 86.—Sectional elevation of injection vaporiser and cylinder head used in the Hein fuel-oil marine engine.

into action a second pump for supplying injection water to the valve, *h*, communicating with the jacketed half of the vaporiser, as soon as the speed of the engine falls below a determined limit; this is necessary to neutralise the effect due to overheating of the outer end and to suppress unnecessary violence of the explosions when working at continuous full load, which then may attain to a pressure of 260 to 280 lbs., with a compression of 90 to 95 lbs. when running on gas oil. The useful cylinder pressure in a 40-b.h.p. size engine averages 70 to 75 lbs., but without water injection the explosion line is much sharper and the power developed less, and in extreme cases it causes the engine to pound.

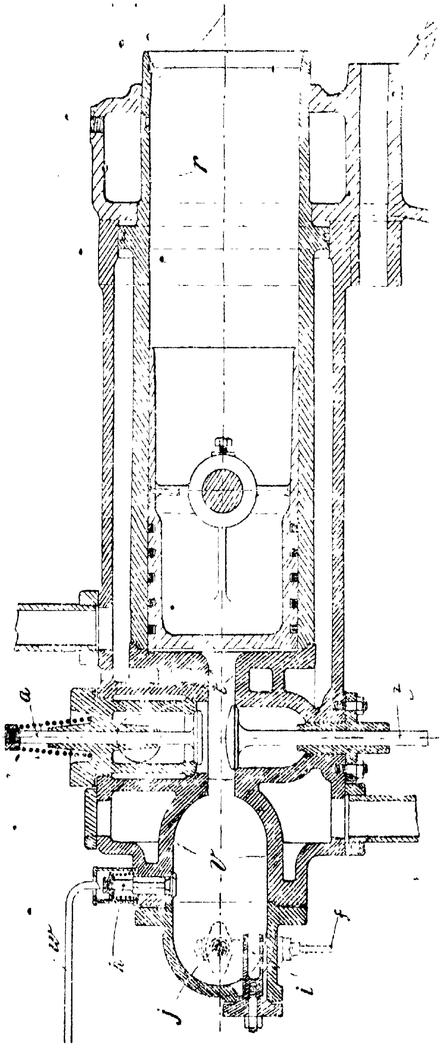


Fig 87.—Part sectional elevation of Crossley residual-oil engine, showing details of injection vaporiser, water feed, automatic igniter, and admission-exhaust valves.

harshly, thus subjecting the bearings to unnecessary pressure and generally reducing the running efficiency of the engine. These remarks apply to all vaporiser engines depending on a heated

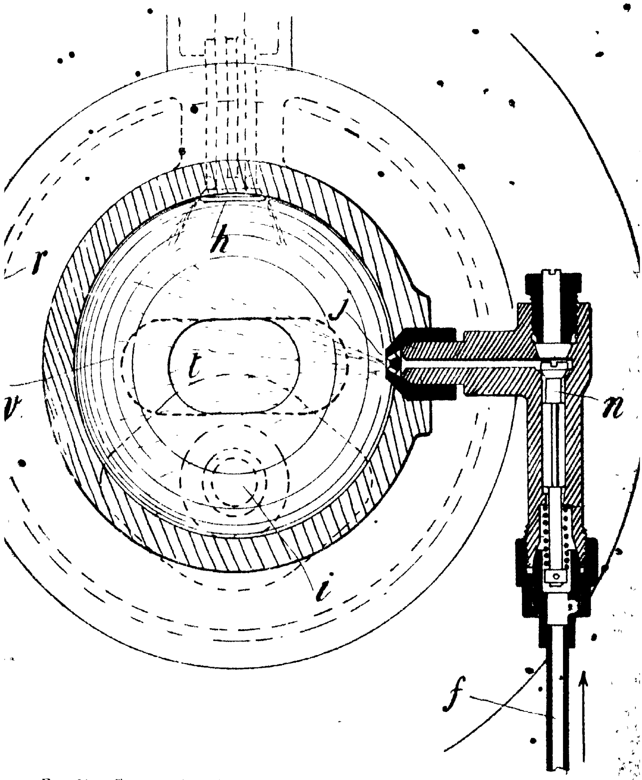


FIG. 88.—Cross-section of vaporiser showing injection nozzle used in the Crossley residual-oil engine.

surface for vaporising and igniting the charge on variable load conditions. If, however, an engine were only required to run at or near its rated load, the vaporiser could be so proportioned as to entirely dispense with water injection; but such an engine would

not run economically on reduced loads, even if provided with an effective igniter. In order to overcome this difficulty, which increases with the size of the engine, higher compressions are used, and the fuel, instead of being injected during the total period of the compression stroke, is limited to a period of 30° to 40°; thus the rapidity of combustion can be controlled to a great extent, provided that a suitable atomiser is used and the compression high enough. In the Crossley engines of really large power, the atomiser valve is opened hydraulically by the charge admitted from a high-pressure supply past a snap-action mechanically-controlled admission valve, the injection period of the atomiser can thus be more sharply determined than by the direct action of a quick-action force pump. This method also lends itself with advantage to engines having multiple cylinders.

The Teasdale oil engine, shown in fig. 89, is fitted with a vaporiser of very similar design to the foregoing, in that the elongated vaporiser, *v*, is separated from the working cylinder by a narrow passage, into which the air-admission and exhaust valves, *a*, *e*, lead. The outer unjacketed half of the vaporiser is ribbed internally, and serves to ignite the charge. The injection nozzle, *j*, is connected by a pipe, *f*, to a variable throw pump, *p*, which draws its supply from a tank, *k*. Other four-stroke pump-injection engines of British make, besides those described, that are capable of running on semi-refined oils, are the Bates (fuel oil), Imperial, National, Fielding, Shardlow (fuel oil), Turner, Walsh & Clark, and others, all of which are of the horizontal type.

In the Westinghouse high-speed vertical engine designed for semi-refined oils of intermediate grade between the lamp oils and fuel-oil residuals, known as gas oil, there are two combustion chambers arranged in series, one serving the purpose of a valve pocket, *t*, but extended all round the cylinder in the form of an annulus (see fig. 90), and the other, an unjacketed extension upwards of about one-half the cylinder diameter, serving the purpose of a vaporiser, *v*. The peculiar feature of this engine is that only about two-thirds of the charge of air drawn into the cylinder is compressed into the tubular vaporiser extension, the annulus, *t*, being located so as to be cut off from the cylinder when the piston has completed about eight-ninths of the upstroke, and as a result of this the rise in pressure for

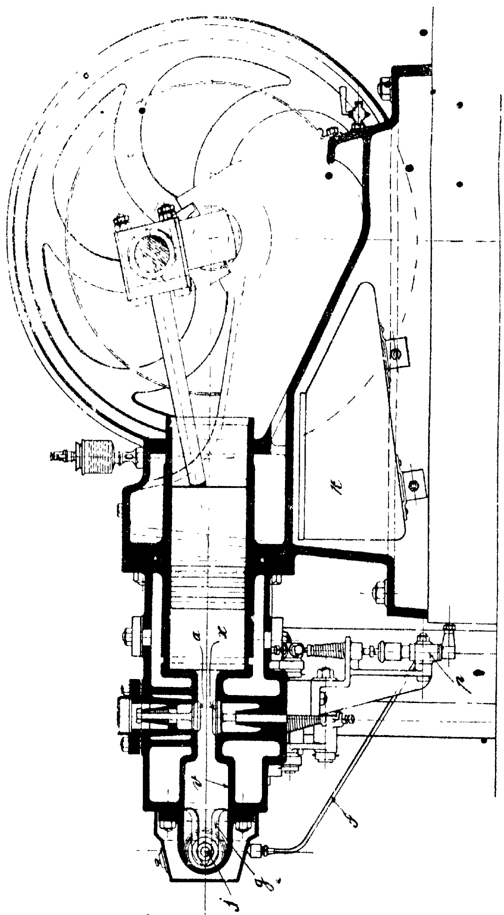


Fig. 89.—Sectional elevation of the Teasdale injection-vaporiser engine for residual oils.

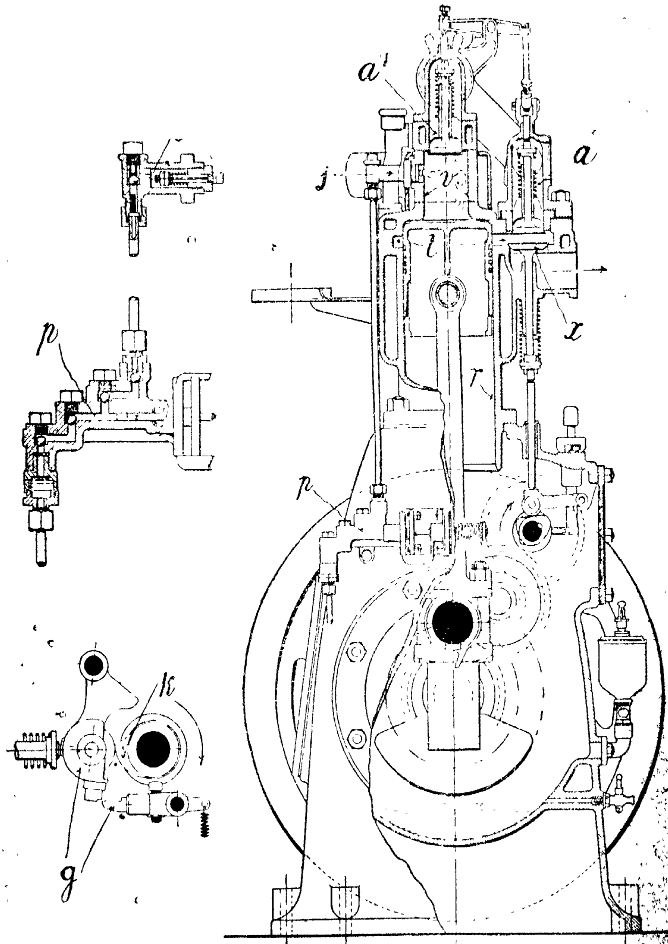


FIG. 90.—Sectional elevation and details of Westinghouse Cross engine, showing injection-vaporising process for heavy oils.

the last ninth of the stroke is increased some 60 per cent. beyond what would result with the total clearance arranged to be at the end of the cylinder; further than this, a more sustained combustion is claimed, as the period of the injection coincides with the period of the stroke during which the annulus is closed. Ignition of the charge is definitely timed by the injection, which commences a few degrees before the end of the stroke and is continued forward, almost to the point at which the annular chamber is uncovered by the piston when working at full load. The fuel is supplied by a variable stroke pump, *p*, regulated by a cam, *k*, and governor-actuated stepped die to an injection atomiser, *j*, provided with a spring-loaded diffusion valve opening direct into the vaporiser. Behind the atomiser valve there is a ball valve, which form of valve is fitted to the pump in duplicate. Air is supplied to the subsidiary chamber, *l*, through a cam-operated valve, *a*, and to the super-compression chamber by the valve, *a′*, also cam operated, *x* is the exhaust valve. The compression in the annulus is 130 lbs., and in the vaporiser 180 lbs., the capacity of each being approximately equal to one-ninth the piston displacement.

The vaporiser illustrated in fig. 91 is the modified form used on the larger sizes of Dudbridge engines for semi-refined, crude and residual oils; in this—adapted for engines of the horizontal type and for powers upward of 40 b h p. per cylinder —the fuel, instead of being drawn past the air valve from a constant-level cistern by suction effect, is injected by a variable stroke pump through the regulator, *p*, and duct, *z*, to the seat of an atomising valve, *a*, the duct, *z*, being of quite small diameter; a variable water injection feed is forced in through another regulator and duct, *w*, on the opposite side. The vaporiser cap, *v*, is unjacketed and jointed to a jacketed combustion chamber extension, *b*, separated from the working cylinder by a short neck, *c*; one of T. G. Smith's automatic igniters, *g*, similar to that used in the Dudbridge vapour-feed paraffin and semi-refined oil engines described in Chapter V., is fitted low down at the end of the vaporiser, and enables the engine to run continuously on a light load without the application of external heat. The main air supply is by a cam- and lever-operated valve located on the top of the cylinder and just over the exhaust valve. Other supple-

mentary air valve spray-feed horizontal engines of large size, such as the Campbell and Tangye, are also capable of running on crude and residual oils.

All engines of the direct-injection vaporiser class require a more or less specialised form of cylinder, and for this reason, if for no other, are ill adapted for conversion as gas engines, and

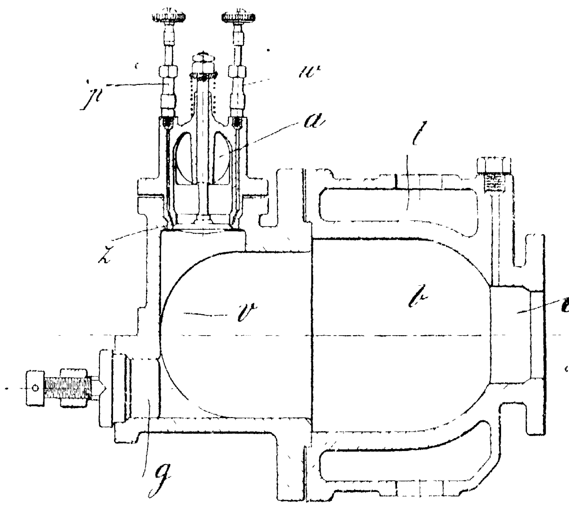


FIG. 91.—Sectional elevation of vaporiser for Dudbridge crude-oil engines, showing shifting-spray injection for fuel and water.

vice versa gas engines, and more particularly vertical engines with multiple cylinders, require considerable reconstruction to convert them to injection-oil engines, and in no case could such an engine be arranged to run successfully on the change-over or interchangeable principle, leaving out the question of cost. As explained in the last chapter, exhaust-heated vaporiser engines lend themselves conveniently for the necessary alterations to run on gas. Tangye's, for instance, make an interchangeable engine with exhaust-heated vaporiser arranged to be started or run on oil-well gas, crude benzene, and to change over to crude

oil, for which there is a demand in the oil-fields; this engine is fitted with a vaporiser that works on the vaporative principle and this being limited to a temperature of 500° to 700°, a portion of the oil—fed by a pump and allowed to spread over a vertical evaporator—is rejected, this, however, is of little consequence, as economy under such circumstances is of minor importance to that of expediency, a more important factor than mere economy being the ability of the engine to be started and run without a lamp or heated surface exposed to the atmosphere.

"Circumstances alter cases" is an axiom of common knowledge, and is particularly applicable when applied to the comparative running costs of different fuels, as these costs are influenced almost as much by the length of running time as by the actual cost of the fuel used. For instance, with a producer gas plant 5.7 b.h.p. can be obtained for one hour at the rate of one penny even at the present price of anthracite—40s. per ton,—when skilfully handled, and thus is seen to work with an efficiency of 0·86 lb per b.h.p. hour; this is clearly, then, one of the most economical fuels for developing powers under 200 to 300 b.hr. when required for day-to-day continuous use. If however, power is only required on alternate days, or even at less frequent intervals, and then for only a few hours at a time semi-refined fuel oil, known as gas oil, for instance, costing 100s to 120s. per ton or more, may be more economical, notwithstanding that the actual difference in fuel costs are as 4·5 lbs. and 1·5 lb for one penny, and the power value as 4 and 2 b.h.p. for one hour for one penny. The reason for this is to be accounted for not only from stand-by losses, but by the convenience of being able to start up at any time at short notice. This in many cases is a factor of even greater importance than the comparative cost of the fuel used. Clearly then, when the hundreds of producer, oil, and town-gas engine installations in use in this and other countries, and the frequent changes in the running conditions are considered, there must be many cases where it would be an advantage to the power user to be able to change from producer gas to low-grade oil, or *vice versa*. This points to the advantage of a vaporiser that can be applied to any ordinary horizontal or vertical gas engine without alteration to the cylinder or the running gear, such advantage accruing

not so much from actual fuel economy as from expediency, and is where a properly designed induction-feed exhaust-heated vaporiser, as illustrated in figs 92 and 93, shows to most advantage. This form of vaporiser, although applicable to any size of engine as usually run on anthracite gas, and adaptable for any number of cylinders from one to four, or even six, is here shown in order to be more explanatory, in somewhat diagrammatic lay-out, this vaporiser has been designed to convert a 16-in. × 20-in. four-cylinder producer-gas engine to run on intermediate grades of residual oils, which can be obtained for less than one-half the cost of refined oils.

As will be seen, the vaporiser is heated by the engine exhaust and arranged for instant starting up from "all cold" on petrol or low-grade benzoline, but is adapted with little change for starting on town gas. The vaporiser is bolted to a special exhaust manifold by the flange x and by the flange l to a pipe connecting to the mixture throttle, there is thus no material alteration to the cylinders

In starting the petrol regulator, r^3, is opened about one-quarter turn to marks shown in the plan view; the running fuel regulator, r^1, is then closed, and of course the water-feed regulator, r^5, also. On being set in motion for an initial turn or two by compressed air, the engine takes up its running on petrol drawn from a float cistern, f, arranged an inch or so below the feed pipe, s, but not necessarily close up to the regulator. After a preliminary run of two minutes or so, preferably with the load on, or, if not, with the ignition retarded, the regulator, r, is opened a full half-turn, the valve, h, meanwhile must be full open to warm up the running fuel contained in the overflow constant-level cistern, d. Low-grade oil is drawn along pipe, p^1, and sprayed into the down-take tube, v, past the seat of the finely threaded regulator, r^1, hot air enters at z^1 to assist in spraying the annular film, the mixture then ascends the internally ribbed composite well, v^1, to the ribbed clearance space, v^2, and thence to the annulus, v^4, connected to the mixer annulus, u, by the passage, v^3, where the vaporised mixture is mixed with air drawn through the venturi nozzle, c; this, as shown in the plan section, is of variable area according to the end-wise position of the plug, g, and throttle opening. The unvaporis-

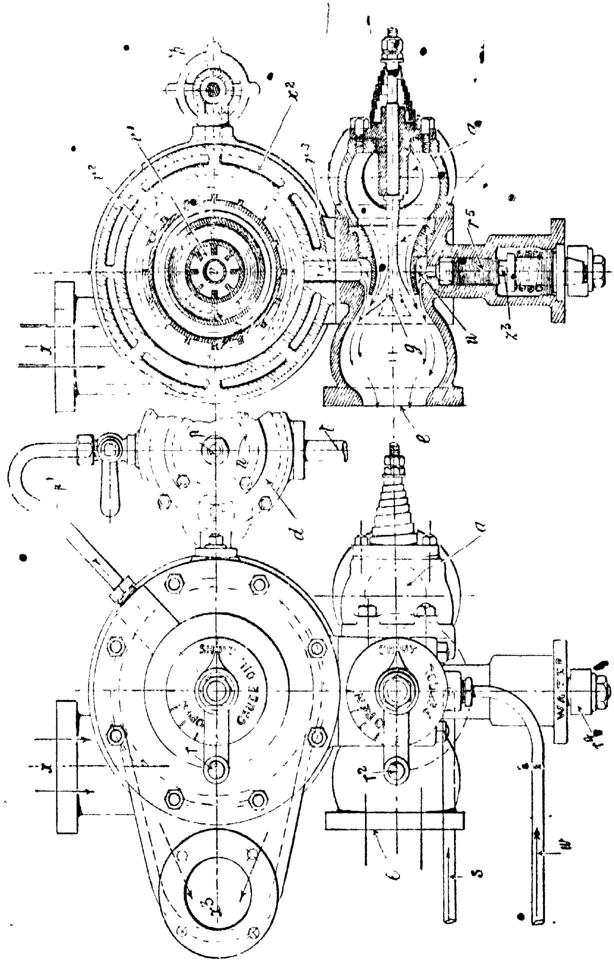


FIG. 93.—Plan views of Butler vaporiser for four-cylinder gas engine.

able portion of the fuel drains away through the pipe, *m*, this being extended down to the bottom of a tank on or below the floor of the engine-room. The amount of fuel rejected depends not only on the specific gravity and boiling point of the fuel used, but also on the load the engine is carrying, the proportion being greater when running below half load than above owing to the reduction in temperature of the exhaust, this, however, can be in part compensated for by retarding the ignition and thus increasing the pressure at the toe of the diagram. The amount of water spray required also varies considerably for different oils, being greatest for crude oils containing a high percentage of the light oils of the benzene and paraffin series, as with the fuel feed, the amount of water spray induced varies automatically according to the suction effect and volume of air drawn in, and this again by the speed and throttle-opening, with the water level arranged a few inches below the regulator, the feed is automatically reduced to a negligible quantity, but is, of course, better shut off when running continuously on light load, its function being to suppress violence of the explosive action due to the high temperature and pressure of the mixture when running at full power.

For an engine of this size the amount of benzoline or petrol required for the preliminary heating of the vaporiser is 8 to 10 pints, this includes a reduced feed of starting oil, to be continued two or three minutes after the fuel-oil feed is turned on, but could be reduced to one-half this by arranging for a supplementary paraffin supply to be turned on to the vaporiser for a few minutes before turning on the heavy oil, as by a third float cistern connected to the feed pipe *p'*. In this connection it should be stated that an engine of this size in order to run on paraffin with a reasonable efficiency would not only require the compression to be reduced to at least 70 lbs., but a bye-pass to shunt quite one-half the exhaust from the engine to the escape pipe direct, this being fitted both with a hand-operated throttle and another connected up to the governor, which method is found to work well on paraffin engines required to take care of themselves on variable load. In regard to consumption efficiency, which at its best is quite 50 per cent. below that of a high-class injection engine at full load and 70 per cent. at half load, this

may be considered as of secondary importance when power is only required for a few hours at a time and at uncertain intervals.

Injection Vaporisers adapted for Two-stroke Engines.—Injection-feed vaporisers are better adapted for two-stroke engines than vapour-feed vaporisers, as the feed can be injected direct to the vaporiser after communication with the exhaust is cut off, there is thus no loss with the escaping gases, nor admixture with the ingoing air, the power duty of the cylinder is therefore greater, owing to the charge both of fuel and air being injected cold, there is no risk of back explosions, nor, in a properly designed engine, of pre-ignition. Two-stroke engines are relatively cheaper than four-stroke engines, power for power, but not so economical, and are besides limited to 40–50 b.h.p. per cylinder. However, in many cases a simplified construction and less first cost count for more than a high economy in fuel consumption and running repairs. Obviously a power-piston controlled series of ports in the working cylinder causes irregular expansion around the port zone, requires more lubrication, and, owing to the need for an early exhaust release to reduce the pressure to below that of the air chamber, the pressure on the piston during the last fourth of the stroke falls away very rapidly. Another set-back to vaporiser, and indeed to all two stroke engines of the enclosed crank chamber and two-diameter piston types, is the large amount of inert gases retained in the cylinder after compression commences, this can be remedied by a separate air-charging pump of larger displacement than the power piston, but involves more than a commensurate complexity. Excessive diluent of inert gas with the air charge partly explains the low power efficiency of the pressure-air admission direct-injection two stroke engine shown in fig. 94, here it will be seen that the relative displacements of the pump, A, and power cylinder, B, are as 3 to 1, and although the extension, T, of the power piston reaches to the bottom of the cylinder at the end of the stroke, the clearance space below the cylinder and between the interstices of the reheater, E, being equal to fully one-third of the charging cylinder, combustion is consequently slow and incomplete, yet owing to the elaborate means provided to prevent heat losses by radiation and conduc-

tion, an extraordinary economy in fuel consumption has been demonstrated (below ⅓ lb. of tar-oil per i.h.p hour) and can

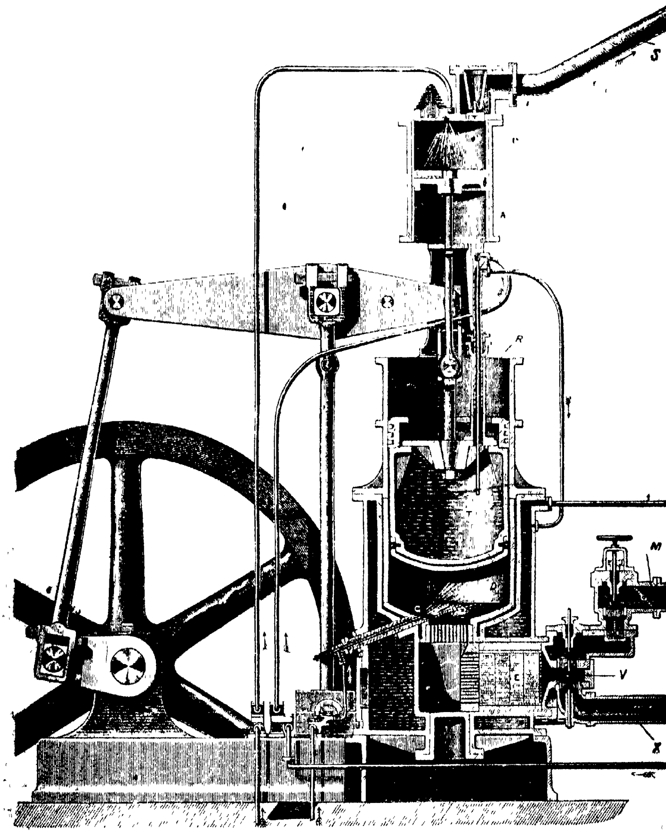


FIG. 94.—Hargreave's two-stroke low-pressure internal combustion injection engine for tar oils.

be explained by the high temperature of the pressure air after passing through the closely packed series of slotted refractory rods, E. In action the fuel charge is first pumped in, then

air at about 40 lbs. pressure from a large tubular interchanger, is admitted for about a fourth of the stroke and then cut off, combustion proceeding at constant pressure, the gases then expand to the end of the stroke, and are exhausted at a few pounds above the atmosphere—according to load and throttle opening—past one of the valves, V, and pipe, X, to the interchanger. To reduce the pressure in the pump, water is sprayed into the cylinder as shown, but is obviously a mistake, the air is delivered to the interchanger *via* the pipe, S, and admitted to the power cylinder along pipe, M, and cam-actuated lift valve, V. Although the bottom end of the cylinder, D, is fitted with a refractory liner, as also the piston, T, and the inner surface attains to a very high temperature, thus conducing to conservation of energy, considerable power is wasted by fluid resistance, notably the pressure-air admission and exhaust valves, which are out of proportion to the size of the power cylinder. This slow-combustion engine with direct-injection feed, although cumbersome for the power developed, is capable of some improvement, but even so is entirely outclassed by modern high-pressure engines, except possibly for tar oil, creosote, and the heavier grades of petroleum residuals.

As before explained, two-stroke direct-injection engines, which are alike adaptable to the horizontal and the vertical form, are all, in so far as the power cylinder is concerned, entirely valveless, all have the same characteristic piston head, and oppositely arranged series of admission and exhaust port openings midway down the cylinder, the depth of the exhaust varying from one-fifth to one-fourth of the stroke, and the admission one-eighth to one-sixth, according to the designed speed. All have an unjacketed globular, bulb, or dome-shaped vaporiser. A characteristic of any of the various forms of vaporiser, disposition, and timing of the injection and other differences in design is that it does not follow that a particular design found suitable for one size of engine can be exactly proportioned for an engine of either a smaller or larger power.

Typical designs are shown in figs. 95–102, of which figs. 99–101 are for comparatively small powers, and not adaptable for running on crude or residual oils. The two-stroke principle is alike adaptable to the horizontal or the vertical form of

injection vaporiser oil engine, but is most favoured in the vertical owing to the reduced weight of base and size of foundation; vertical engines, again, lend themselves better for coupling up in multiple. Although there have been literally hundreds of variations in design, having for their purpose a more positive displacement of the inert gases, involving either a bigger air pump or

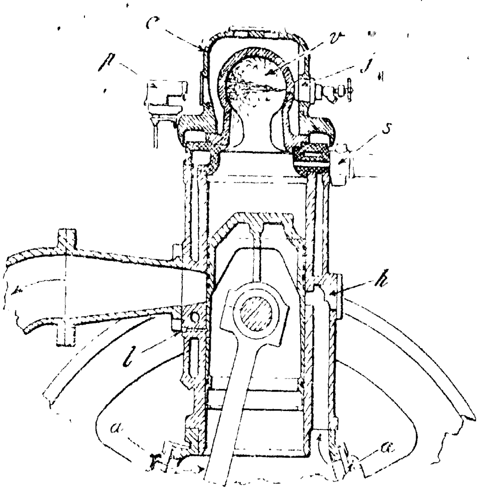


FIG. 95.—Section showing method of connecting the injection nozzle to the vaporiser of the Robey two-stroke residual-oil engine.

the use of air-admission valves, double-ported piston control has survived. The form of vaporiser, method of attachment, form and location of the injection nozzle, and in a few cases where an atomiser is used, the particular design of this, constitute the principal variants in the several makes of this useful class of engine.

The form of vaporiser most generally adopted is the bulb or globular, with a more or less contracted neck, as shown in figs. 95, 96, and 98–101. The vaporiser used in the Robey residual-oil engine is of globular form, but with the neck widened at the base in line with the ports below, this so that the upward-

deflected air shall enter the globe and sweep out the products of combustion. The vaporiser, which constitutes a large proportion of the compression space, is clamped to the jacketed cylinder cover by a heavily-flanged cowl, *c*, this also carries the injection nozzle, *j*, which makes a small ground joint with the vaporiser. The injection feed is supplied by a variable stroke pump driven from a governor-controlled pivot block on a rocking lever. The nozzle is formed to cause the charge to be injected with a rotary movement, the spray thus expands by centrifugal action. To prevent pre-ignition on full load, the injection commencing 40° or so before the end of the stroke, water is sprayed in from a nozzle carried by the plug, *h*. A similar design is shown in fig. 96, but here the vaporiser, *v*, is smaller, and separated from the cylinder by a long contracted neck formed in the jacketed cover. In this engine the injection nozzle is inclined so as to project the spray nearer up to the crown of the bulb. There are other differences, one of which is the method of holding down the bulb by a flange and set of studs; another is the jointing of the cylinder cover, the jackets being connected by an elbow. Engines of this make, when over 40 b.h.p. per cylinder, are constructed to work with a compressed-air injection atomiser. A somewhat identical effect can be obtained by an atomiser nozzle worked at very high pressure, and in the Petter residual oil engine (fig. 97) this method has been adopted in combination with a compression space, of which only one-third is unjacketed, this portion taking the form of a small cap, *c*, held down by

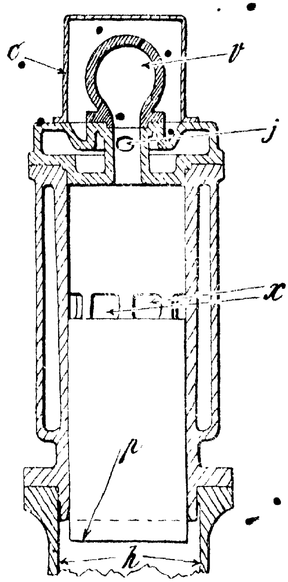


FIG. 96.—Globular vaporiser used in the Beardmore marine oil engines.

a ring, *r*. As in the preceding example, the injection nozzle, *j*,

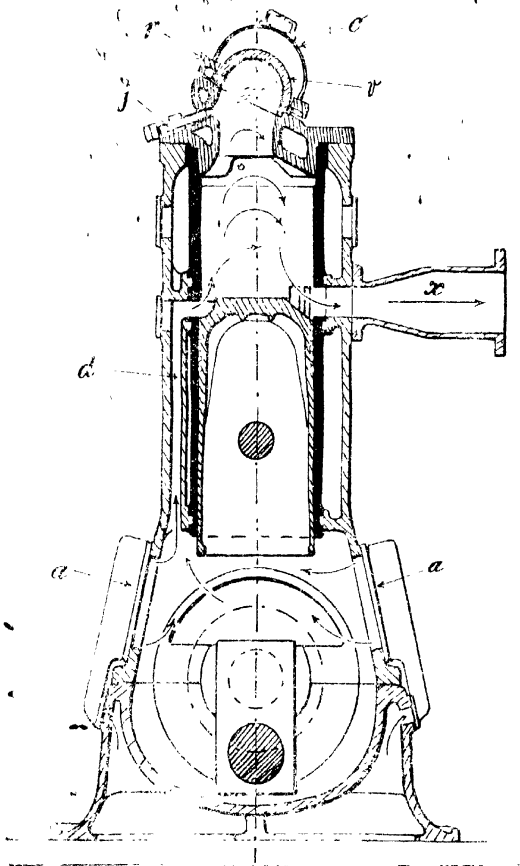


FIG. 97.—Section showing vaporising process used in the Petter two stroke engines for semi-refined and residual oils.

is inclined, but differs in having a very restricted jet orifice, small enough in fact to require a pressure of nearly 2 tons to

force the jet through during the period limited to some 30°. Owing, therefore, to the reduced heated surface, higher compression, and minute subdivision of the feed, combustion can

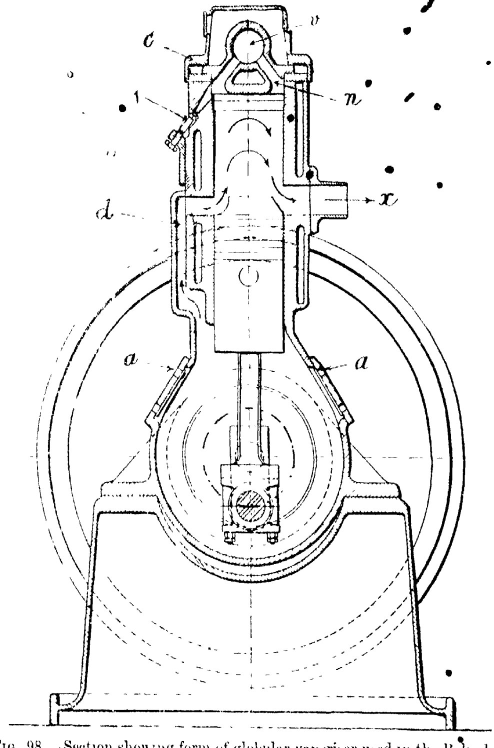


FIG. 98. Section showing form of globular vaporiser used in the Bolinders two-stroke engine for semi refined and residual oils.

be, and is, controlled by timing the fuel injection without water spraying in the cylinder, which is of course an advantage at sea, and even where pure water is obtainable, as its effect on the cylinder, unless very sparingly used, has the tendency to combine with the oil film, and with some fuels, to cause corrosion. In

the Bolinders engine (Rundlof's Patent, 12790, 1903), which for many years held leading place under this class, the vaporiser is globular and connected to the cylinder by two inclined passages

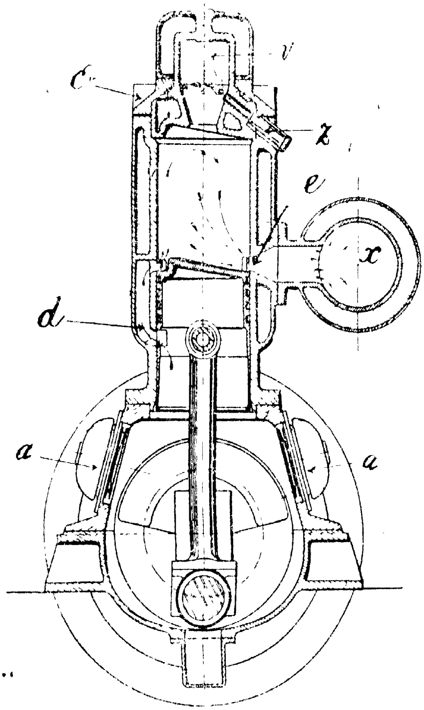


FIG. 99. Sectional elevation of Ailsa Craig two stroke marine engine for heavy oils, showing vaporiser and cylinder cover cast in one piece.

n (fig. 98), under one of these is arranged the nozzle, j, so as to project the spray in such manner as to sweep out the burnt gases, and thus better to determine the point of ignition by the injection. A feature in this engine (Swedish) is a specialised system of duplex-injection pump gear, by which the motion can be reversed with surprising ease.

The weak point in all engines of this class is the unjacketed

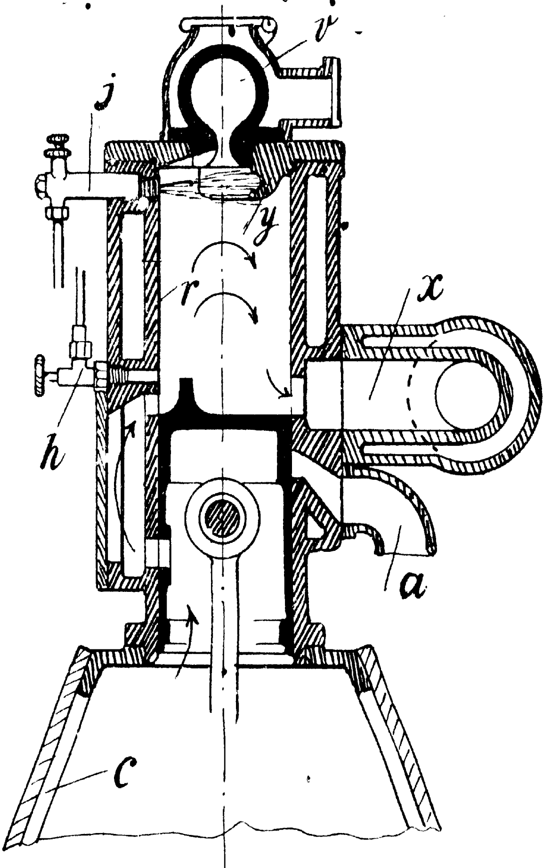


FIG. 100. - Vaporising process used in the Marmot two-stroke marine oil engines.

vaporiser, which subjected to both a high temperature and the full force of the explosions, sooner or later, owing to the stresses

set up by unequal expansion, shows signs of deterioration, and, as would be expected is not entirely free from liability to fracture. For this reason it is the usual practice to clamp it on to the cylinder cover by a loose ring or by a heavily-flanged cowl, thus minimising fracture at the neck and facilitating renewal. In the Ailsa Craig engine, shown in fig 99 the neck of the vaporiser, c, is jacketed, and constitutes the cylinder cover, this in turn is clamped on to the cylinder head by a

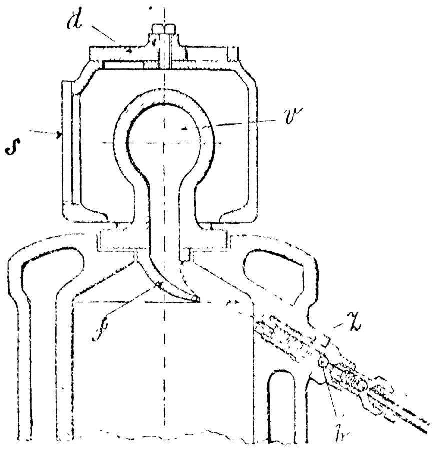


Fig. 101 Sectional elevation of the Cudell two-stroke bulb-vaporiser injection oil engine

loose ring, e, in this design also the vaporiser is self-contained with the injection nozzle, z, arranged in an inclined position so as to project the spray high up on to the more heated surface Obviously the injection should be straight up, but as this is impossible with a centrally arranged vaporiser, a compromise can be effected by arranging the vaporiser in an inclined position somewhat as shown in fig 97, or with inclined portways, as in fig. 98, thus enabling the spray to be projected right on to the hottest part, or nearly so, and to be more uniformly vaporised this consideration favours a horizontal disposition, as shown in fig 106. A somewhat similar effect can be produced by arranging

a ledge projection opposite to the nozzle, as shown in figs 100–102, and although having the desired effect in cylinders of the smaller sizes, with the injection commencing at an early period of the compression stroke, this method is not so effectual for the heavier oils, as the spray does not come into immediate contact with the bulb until late in the stroke In the Marmot engine this projection, *y* (fig 100), forms a part of an unjacketed cylinder

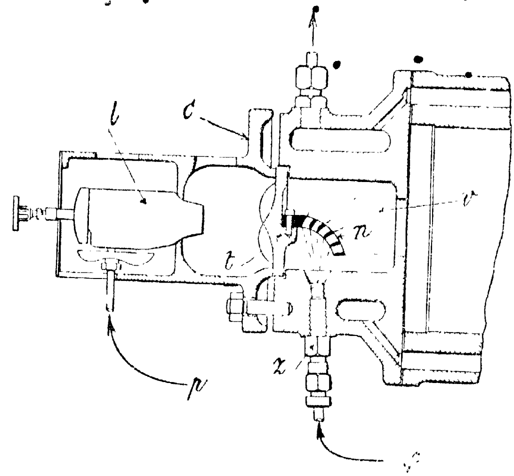


FIG. 102 Sectional elevation of Bergsunds two-stroke engine for heavy oils.

cover, and in the Cudell engine (fig. 101) is integral with the bulb, *v*, the nozzle, *z*, in this instance being inclined so as to project part of the spray up into the bulb, this would seem to be the more effective plan, but has the disadvantage, as before, in limiting the function of the bulb more as an igniter than a vaporiser. Here is shown the details of the injection plug, with duplicated ball-check valves and detachable nozzle with simple form of spray orifice. The deflector principle is shown in modified manner in the Bergsunds engine (fig. 102), here the vaporiser or compression space, *v*, is a jacketed extension to the cylinder, in which a curved deflector of grill formation is bolted to an un-

jacketed cover, t, held in place by the lamp cowl, c, in this engine (horizontal) the fuel is injected on to the grill from below. Paraffin can be used in the smaller sizes of any of these engines with a copious injection of water, the method generally adopted being to inject either by a pump, as in the larger sizes, or direct from the cylinder jacket to a nozzle either to the admission port, as at h in fig. 95, or above the port zone as at h in fig. 100. Besides the two-stroke direct-injection engines described, needless to say there are a number of others, including (British) the Cyclops (Clarke Chapman), Coates, Kromhout (Plenty & Co.), Martins, Mitcham, Nat, Pollock, Standard (Simpson & Strickland), Walsh & Clark, (American) Blanchard, Meitz & Weiss, Primm, Remington, mostly adapted for semi-refined oils, known as distillate, (Danish) Tuxham; (Norwegian) Grei, (Dutch) Kromhout, (Russian) Zkval, (Swedish) Avance, Balder, Dux, Munktell, Primus, Svea, Skandia, (other countries) Fafnir, Voightman.

Compressed-air Injection Atomisers.—With the initiation of compression by Boulton in this country and Beau-de-Rochas in France, acting independently, in 1868, the latter including in his specification a clearly described method of carrying this into effect, also a statement demonstrating the theoretical and practical advantages that would result from compressing a charge of explosive mixture before ignition, so R. Diesel in his British Patent, 7241 (1892) stated that a further economy could result from first compressing air to such temperature that a pulverised charge of fuel would ignite spontaneously during the process of injection, thus instituting the constant-pressure principle now so widely adopted in high-compression atomiser injection oil engines of large power. The method of injecting the charge of fuel into highly compressed air by a super-compressed charge of air, so difficult to dispense with, was also described by him in another patent three years later, this being quite ten years before the advantages of this system were fully recognised. High-compression oil engines have the unique property of running on low-grade liquid fuels without a vaporiser, but in order to do this they must be worked at a pressure high enough to produce spontaneous combustion by heat transmitted to the charge dynamically. This imposes a condition of some difficulty, as with the most perfect form of

atomiser compressions ranging from 450 to 550 lbs must be used in the working cylinder, and the fuel be injected by the action of an air blast supplied at a pressure of not less than 700 lbs., and for some of the more refractory fuels as high as 900 lbs per sq. in. Yet, despite the necessity for feeding the fuels against this pressure, and the power absorbed in compressing the injection air, in volume equal to approximately one-tenth of the main charge, also the necessity for specially high-grade workmanship, the thermo-dynamic advantage gained with this system is so considerable, and the starting and control so simplified, that for large powers there is every reason to suppose that it will continue to hold its present pre-eminence.

The high-compression principle is equally well, or even better, adapted to the two-stroke than the four-stroke cycle of operation, as the necessary volume of air for ensuring a thorough scavenging effect can be blown through the cylinder without risk of carrying away to waste any of the fuel injected for the succeeding charge.

Further, high compression renders it possible for an engine of either construction to be as quickly started from all cold as an engine run by town gas or petrol. However, much ingenuity has been directed towards keeping down to the lowest possible limits this necessity for the use of high compressions, with which object the form of atomiser used has received a particular share of attention. The most successful method so far is to supply the fuel charge to the annular clearance space surrounding the guide sleeve used for a plain stem or needle valve, which on the valve being raised about 1 mm. off its seat against the pressure of a stiff spring is forced into the compression clearance space—representing about one-twenty-fifth of the stroke in a continuous jet for a period commencing at a few degrees before the termination of the compression stroke—to from 10° to 30° of the working stroke, this varying according to the load on the engine. The period of fuel injection is obviously determined by the quantity supplied by the feed pump to the atomiser, and is subject to regulation by the governor to suit the load; the space above or behind the injection valve seat is continuously open to the super-compressed supply of injection air, which at first forces the fuel charge in various admixture therewith into

the cylinder compressed charge, and then continues as an air jet until the valve closes; this is the usual practice, but in some engines of the larger sizes the cut-off or admission period of the air blast is simultaneously controlled according to the amount of fuel admitted; this, although of minor importance with the average varying load, has an advantage on light loads, for the reason that the high pressure and comparatively low temperature injection air considerably cools the cylinder charge during admission in expanding down from 700 to 500 lbs or so, and consequently reduces the efficiency of combustion; there is further to be taken into account the power absorbed in compressing any surplus of injection air required for atomising the fuel charge. The form of diagram taken from an engine actuated in this manner shows little or no initial increase of pressure above that of highest compression, which may be as low as 450 lbs for running on semi-refined oils with an effective atomiser, but more usually attains to 500 or 550 lbs, which pressures are necessary for economy in working on residual oils irrespective of the form of atomiser used or pressure of the injection air.

The volume of free air required for injecting and atomising the fuel charge varies from 10 to 12 per cent of the sweep of the power piston, and is usually compressed to the requisite pressure in a two- or three-stage pump; this obviously constitutes an important essential to high-compression engines without vaporisers, and to entirely avoid, or at least to minimise, this essential many and various alternative methods have been tried with varying success; the mechanical or solid jet atomiser is one of these, but is more susceptible to derangement from choking of the injection orifices, from pump leakage due to the excessive pressure necessary, and to wear of the actuating gear; true, in somewhat modified form mechanical atomisers are used in several makes of residual-oil engines capable of developing 100 b.h.p. or so per cylinder in combination with a small vaporiser, such as the Bates, Crossley, Hornsby, Ruston, Petter, Shardlow, and other engines, also air-injection atomiser engines working at a considerably reduced pressure, but requiring as before a small vaporiser, such as the Blackstone and Vergne residual-oil engines. There is another method, in which air from the main

cylinder is received into a small super-compressor on the cylinder head, by which means sufficient air can be boosted to the requisite pressure for forcing in and atomising the charge, but on this system (used in the Twinckler injection engine) the air-injection pump must be duplicated for each cylinder, and therefore can only show to the best advantage in single-cylinder engines.

There is considerable diversity in the particular form of atomiser used in super-compressed-air injection engines, so much depending on getting the maximum comminution of the fuel, to this end a method much favoured is to cause the charge to acquire a high velocity vortex motion by the process of injection, somewhat as adopted in pressure-oil burners for furnaces, the resulting centrifugal action has not, however, an equal advantage as in a furnace, the space being so confined in the small clearance over the piston when at the end of the stroke, and in practice it is found better to cause the air and oil to be injected together, for this purpose the atomiser is in many cases formed with a double annular space both converging to a plain mitre seat for the end of the stem injection valve, in other designs the charge after admission past the fuel valve is more thoroughly dispersed and further pulverised by being forced through a variously disposed series of fine apertures in a steel disc or plate located close up to the valve seat, this method is somewhat inefficient owing to interference with the injection flow from deposition of incombustible particles. A typical atomiser[1] for a vertical cylinder is shown in fig 103, here it will be seen that the fuel is delivered to the atomiser, against the full pressure of the injection air, through a pipe, *f*, during the compression stroke of the working piston, when at, or a few degrees before, the end of the up-stroke the stem-valve, *j*, is sharply raised about one-twentieth of an inch by the cam lever, *k*, thus allowing the charge of fuel to be blown into the clearance space containing the cylinder charge of air compressed to within 30 or 40 lbs. above or below 500 lbs. per sq. in., by a blast of super-compressed air at from 700 to 900 lbs., and in volume equal to approximately one-twelfth of the main compressed charge; this air is first supplied by a two- or three-stage pump to a seamless steel separator chamber (known as

[1] The illustrations in this chapter are taken from *Gas and Oil Power*

a bottle) to permit condensed steam and oil vapour to settle before admission to the atomiser along the pipe, *d*. The period of the lift is usually from 5° before the zero line till 30° after, and is not usually under governor control. The volume of the fuel charge is determined by the feed pump, either by varying the stroke or by holding open the suction valve, the inlet and

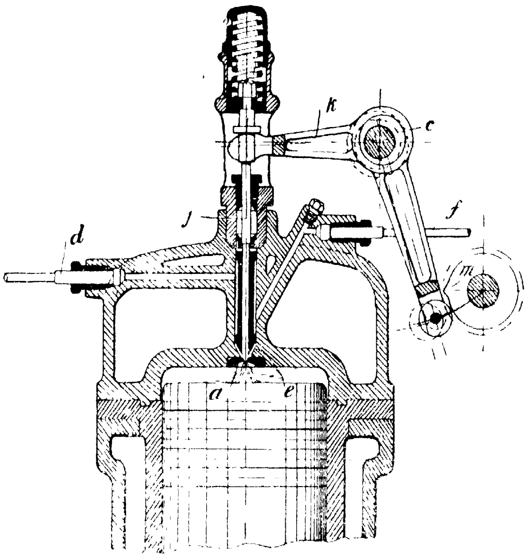


FIG. 103.—Cross-sectional elevation of cylinder, showing details of compressed-air atomiser and fuel-injection valve-gear used on the Flag-Diesel residual-oil engine.

outlet valves being invariably in duplicate. In the example shown, the duration and extent of the fuel-valve lift can be adjusted either by hand or governor control, by a part rotation of the eccentric, *c*. a variable cut-off can also be obtained by changing the point of connection by a sliding block and link motion, as adopted in large-power gas engines. The advantage of synchronous governor control between the feed pump and injection valve shows more on light loads, as then the period

of fuel injection is always less than one-half, and may be as low as one-fourth, the period that the valve is held open, consequently more than double the volume of super-compressed air is then used than is really necessary, but, more important still, the surplus cool air on expanding considerably cools the mixture and otherwise interferes with combustion, this is, however, more inimical to efficiency with the heavier oils In the atomiser shown in fig. 103 both fuel and air are supplied to a single annulus around the valve sleeve, consequently the oil charge to a great extent settles to the bottom, and is injected with little or no air admixture, the sleeve terminates in a cone with inclined grooves, c thus the oil on its way to the valve seat acquires a rotary motion, which tends to disperse and more thoroughly atomise the spray, the piston head, however, assists in the process of vaporisation, and is usually very thick, partly to prevent fracture it is true, but more for the purpose of presenting a more highly-heated surface. In general practice a steel disc, *a*, is screwed either into the head of the cover, or on to the end of the atomiser plug, or, again, is held in place by a ring nut as shown—this of course is to ensure a positively pressure-tight seat to the fuel valve. In another example (fig. 104) the atomiser is shown arranged horizontally between the air-admission valve, *a*, and the exhaust valve, *x*; from this the fuel spray is projected from a single orifice for a variable period on the opening of the stem valve, *j*, by a blast supplied by the pipe, *d* The fuel and air are supplied at points at right angles, and pass along grooves in the sleeve surrounding the valve, by this means the liquid is delivered more to the upper side of the valve seat, so as to be driven into the cylinder in a continuous jet. In another form of atomiser (Fielding's) there are two annuli, and as the fuel is caught by a lip on the under side and forced to the inner space, both fuel and air pass along together to the valve seat. The atomiser used in the Hasselman two-stroke engine (fig. 105), known as the Polar-Diesel, differs from general practice, as to the special form of sleeve used. In this, on the opening of the stem valve, *j*, the fuel contained in the space surrounding the bottom of the sleeve is forced up a series of openings to a short inner annulus next the stem, whence it is carried downward around

the valve stem by the air blast from *d*, and projected into the clearance space from a series of diverging openings, *y* contained in the nozzle plat screwed on to the end of the atomiser stem. As will be gathered from the form of the piston head, these engines work by piston-controlled air admission and exhaust, which is a method having at least one particular advantage,

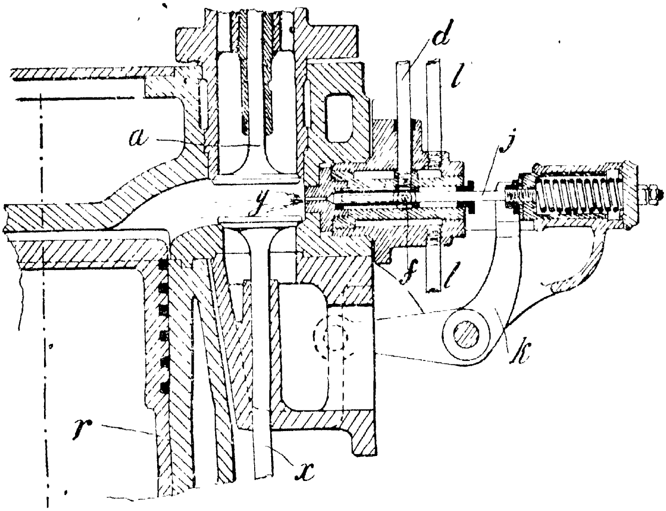


FIG. 104.—Cross sectional elevation of cylinder, showing details of air, exhaust, and fuel-injection valves used on the American-Diesel residual-oil engine with compressed air, fuel injection atomiser.

as it leaves the cylinder head free of other than the injection and starting valves, the accommodation of the necessary valves including fuel starting air admission and exhaust on the cylinder cover being the worst feature in all four-stroke air-injection engines.

For burning tar oil, creosote, and the heavier residuals from crude oils having an asphaltum base, either the cylinder compression and pressure of the injection air may be made higher, or the injection valve may be duplicated, one being timed in advance of the other and connected up to a lighter grade of oil;

or again, a single injection valve may be connected up to separate feed pumps, one, as before, being timed a few degrees in advance to feed a small supply of starting or ignition oil. With each of these methods it is clear that either the feed pump or the injection valve must be duplicated. Duplex injection has been adopted in the Blackstone residual-oil engine (Carters), but in a different way, the purpose here, however, is not only to keep down the cylinder compression as well as the air and oil injection pressures, but to be able to run on the cheapest grades of liquid fuel. According to this system, shown in the illustrations (figs. 106–108), there is realised one of the most ingenious compromises between the high-compression air-injection atomiser and the direct-injection vaporiser types of engines, the object being the attainment of a definitely timed ignition and effective combustion of the charge, but without the necessity for such high compressions as used on the Diesel system. In this engine the cylinder compression has been reduced to 150 lbs. and the injection air to 350 lbs. by the use of two atomisers, one of which is

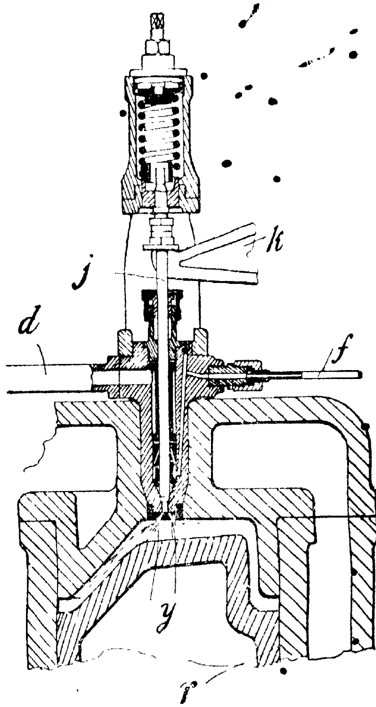


FIG. 105. Cross sectional elevation, showing details of cylinder head, piston, and compressed air injection-atomiser valve used in the Polar-Diesel two stroke engine for residual oils.

arranged to inject with a slight lead sufficient of the working charge into a small vaporising bulb, *v*, to run the engine empty and to maintain the bulb and igniter rod, *g*, automatically and continuously at the required temperature for ignition of the firing charge under all variations of load. The second atomiser is brought into action to a variable extent according to the load on the engine, the injection feed for this being under governor control. Fuel from the main atomiser is injected directly into the cylinder clearance space, and is vaporised and ignited partly

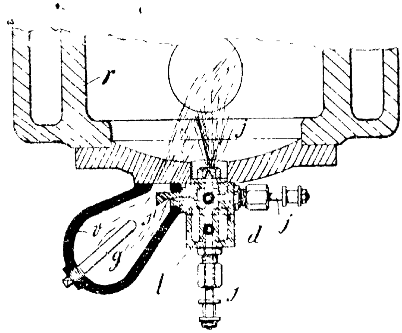


FIG. 106.—Sectional plan showing ignition and vaporising process used in the Blackstone residual-oil engine with double jet compressed air atomiser.

by compression, partly by a projection on the piston head, but more from direct contact with the flame projected from the bulb across the issuing spray from the secondary atomiser. The fuel for both atomisers, *j j′*, is fed by a variable stroke pump during the compression stroke to cavities behind the stem-injection valve seats, whence it is blown into the bulb- and cylinder-compressed charge by a blast of super-compressed air supplied by a two-stage pump, *c*, to the inlet, *d*. The primary injection valve is opened a little in advance, but only for such period as necessary for maintaining the bulb at the necessary temperature for igniting the primary charge; the main injection valve is then immediately opened for the admission of the working charge. The primary vaporiser or ignition bulb, *g*, must be heated externally at starting, but this is of small consequence in a single-

or double-cylinder horizontal engine, although in a vertical engine of large power with multiple cylinders it would be considered detrimental under average conditions. This difficulty can, however, be got over by using a modified form of vaporising bulb, arranged to be heated at the start electrically by a resistance coil. As shown in figs 107 and 108, the main air

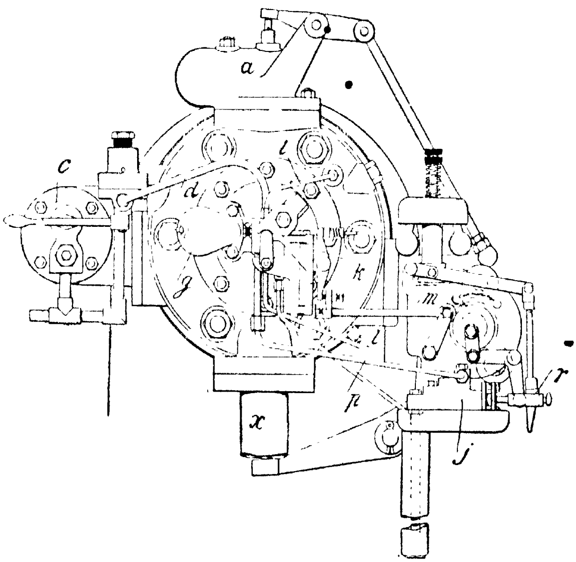


FIG. 107. End view of Blackstone air-injection engine for residual oils, showing details of governor-controlled fuel pump and injection-valve operating gear.

admission and exhaust valves, a x, are situated one over the other, and cam operated, the cylinder cover is unjacketed; the piston also is provided with a thick extension, n, both of which assist in the process of vaporisation and combustion. The two fuel-injection stem valves, j, are operated by a quick-release cam and push-rod gear, m, and rocker levers, k, the valve, t (fig. 108), opening slightly in advance of the valve, f. The plunger of the triple-check valve feed pump, j, is operated

with a variable stroke by means of a wedge, *r*, held in suspension by the governor between the plunger head and the cam lever The charge from the fuel pump is delivered along the pipe, *p* to a cavity communicating with both injection valves, as also compressed injection air from the two-stage pump, *c*, along the pipe, *d*. This is shown more clearly in fig 108, the two pipes, *l*, are for circulating water, and communicate with top and bottom of the cylinder jacket.

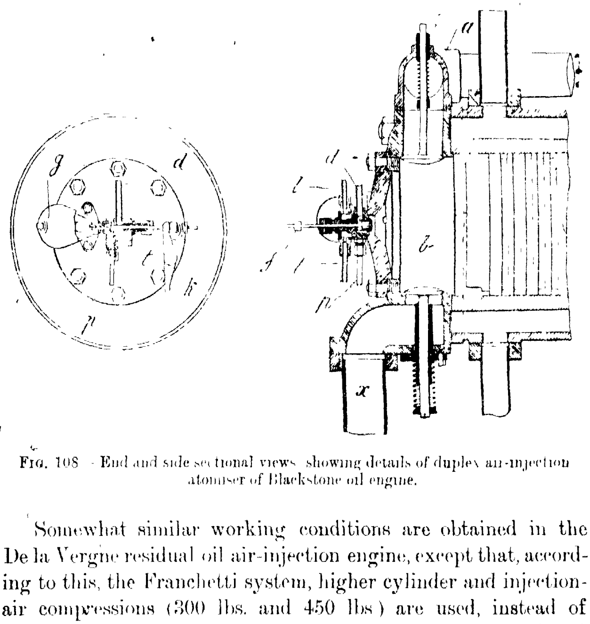


FIG. 108 - End and side sectional views showing details of duplex air-injection atomiser of Blackstone oil engine.

Somewhat similar working conditions are obtained in the De la Vergne residual oil air-injection engine, except that, according to this, the Franchetti system, higher cylinder and injection-air compressions (300 lbs. and 450 lbs) are used, instead of 150 lbs and 350 lbs as in the Carter system; also a combined vaporising and ignition unjacketed dome, *v*, is located directly in line with a single fuel atomiser, *j*, on the opposite side of the compression space between the cam-operated air admission and exhaust valves, *a x* (*vide* figs 109 and 110), by which means the timing of vaporisation and ignition of the charge can be positively controlled by the opening of the injection valve.

Injection air is supplied to the atomiser, through a pipe, as indicated from a two-stage pump, *d*, driven from an eccentric on the main shaft (fig. 110), and having a capacity of practically 0·06 of the air admitted to the combustion cylinder. The amount of fuel forced into the atomiser during the compression stroke is regulated by a variable stroke pump, *p*, under control of the governor *g*, spring, *r*, and sliding fulcrum block, *t*,

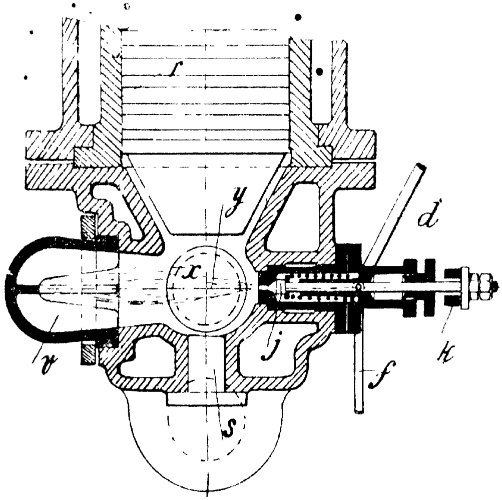


FIG. 109. Sectional plan showing vaporising process used in the De la Vergne residual-oil engine with compressed-air atomiser.

between the cam and pump-operating levers. The inlet, *d*, for the injection air is opposite to that for the fuel supply, as shown at *f*, in fig. 109. The largest power at present obtained from a single-cylinder horizontal engine of this make is 200 b.h.p., and in this the guaranteed consumption with residual oil is equal to 0·6 lb. at full load, and from 0·65 to 0·75 lb. for loads between 0·55 and 0·25, the rated power of the engine; but on test with an intermediate grade, having a sp. gr. of 0·86, a consumption as low as 0·408 lb. has been obtained, and with Californian crude (0·95 sp. gr.) 0·484 lb., from which it

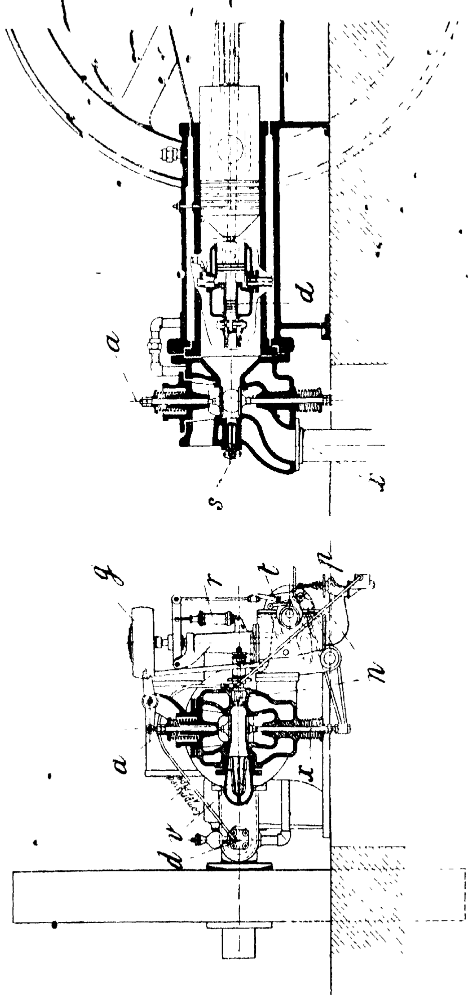


FIG 110.—End and side sections, showing details and general arrangement of operating gear used on the Vergne air-injection oil engine.

would appear that for intermediate powers, and where an externally-heated vaporiser for starting presents no difficulty, this type of engine should have some advantage over the high-compression vaporiserless type (Diesel) owing to the possibility for a lower-grade scale of workmanship to be used in its construction

Before concluding the consideration of air-injection high-compression atomiser engines, the Brons high-compression residual-oil engine may be appropriately described, as although differing in operation from the Diesel principle in using neither injector air nor fuel under pressure the method of igniting the charge by the heat of combustion is the same In the atomiser used on this rather unique system (*vide* figs. 111 and 112) the fuel, which may be crude, semi-refined or of the lowest grades known as residual or fuel oil, is fed to an internal combined atomiser and vaporiser cup *e* along a pipe, as at *f*, from a cistern of the constant-level type arranged about 2 ft above the cylinder head to the clearance space around the needle valve, *e* this together with the combined fuel- and air-admission valve, *n* are opened simultaneously, or nearly so, during the admission stroke of the working piston by cam levers, *k k'*, and thus admit a charge of fuel in the form of spray to the vaporising cup. This cup is open to the compression space of the working cylinder, *r*, through a series of fine apertures near the bottom, the *modus operandi* of this process is such that at the termination of the compression stroke the heat evolved (approximately 1000°–1200° Fahr.), by compressing the cylinder charge to 480–500 lbs., is prevented from vaporising the whole of the fuel

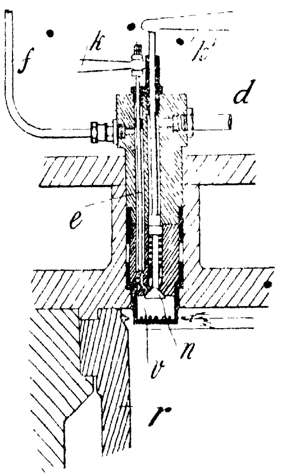


FIG. 111 —Brons Compression Vaporiser

admitted owing to the shielding effect of the perforated cup, but immediately following the ignition of that part of the fuel vaporised during compression, the resulting combustion and increase of temperature cause the remainder of the charge to be vaporised and ignited, complete combustion of the fuel charge admitted then resulting in an initial pressure of 140–160 lbs. above that of highest compression. With this apparently very simple method of safely using a very high compression with fuel- and air-suction admission, the outstanding feature is the surprisingly low consumption obtained, such, indeed, as in ordinary practice and with comparatively small engines, averages but little above ½ lb. of intermediate or semi-refined oil per b.h.p. per hour, in fact a consumption lower than this (0.487 lb.) has been obtained in an 8-in. × 10-in. engine, at 310 r.p.m., running on a 15 b.h.p. load. But whether this system is applicable for the development of larger powers has yet to be proved, the surprising fact remains that combustion can be controlled in this truly remarkable manner under certain limitations.

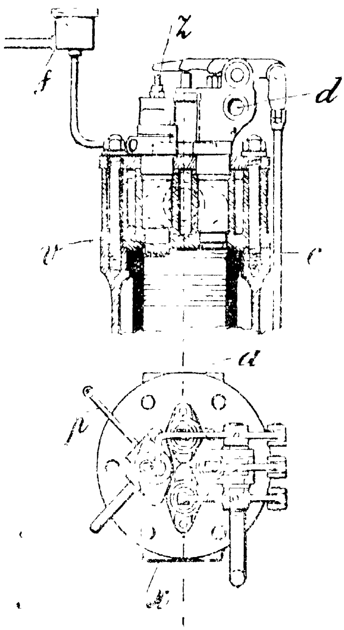


FIG. 112.—Sectional elevation and plan, showing general arrangement of the Brons Compression Vaporiser process for heavy oils.

With a similar object in view a modified form of high-compression oil engine of the injection-atomiser class has been experimented with, in which the necessity for supplying the fuel

charge under pressure is also obviated. According to this system super-compressed air is not admitted to the atomiser until after the fuel has been fed in with the result, judging by the diagrams, that the injection process into the cylinder charge of highly compressed air is not so gradual as can be obtained on the pressure-admission system, when, with a properly adjusted injection of the fuel charge, there is little or no rise in pressure beyond the point of highest compression.

CHAPTER VII.

ADMISSION AND EXHAUST VALVES USED IN PETROL, GAS, AND OIL ENGINES; WATER COOLED EXHAUST VALVES.

FOR engines actuated by gaseous pressure generated within the working cylinder from the combustion of explosive mixtures the ordinary distributing valves, which have proved so successful in the working of steam engines, are not so well adapted, owing to the pressure generated within the cylinder being greater than the pressure at the back of the valve

Admission and Exhaust Valves.—In the early atmospheric type of gas engine and in some compression engines of more recent construction flat slide valves have been used with a fair amount of success, these, however, have not been of the pattern ordinarily used in fluid-pressure engines such as can be held up to the cylinder face by the pressure of the actuating fluid, but in all cases have been formed with two parallel sides, each of which necessarily had to be accurately machined to enable the valve to slide between the cylinder face and the retaining cover. The principal reason for using this expensive form of valve in the earlier engines was to obtain reliable ignition of the mixture within the working cylinder by a flame, the valve for this purpose being provided with a flame pocket, by which means a small portion of inflamed mixture was capable of being brought into contact with the contents of the mixture at the correct moment for igniting the charge under pressure, it will be understood that the slide-valve as well as the spring-retained back cover, as used in these engines, were generally provided with separate air and gas ports in addition to the necessary flame flue and pocket.

In practice, the use of slide valves has been found to be attended with considerable inconvenience and inefficiency on account of leakage of gas into the engine-room, from fumes from the pilot flame and ignition port, and from loss of power through mis-ignition of the cylinder charge. The valves, moreover, required very careful adjustment, and were expensive to keep in repair, re-facing being found necessary after a few hundred hours' working. In the atmospheric type of gas engine, as made between the period of 1860 to 1876, and in some non-compression engines of a later date, slide valves were also used, and provided a means for obtaining a quick cut-off to the mixture supply and suction of ignition flame.

Although piston valves and, in some cases, rotary valves of disc and cylindrical form have been used in engines working on four- and two-stroke cycles, the poppet valve remains to-day practically alone, this type of valve, with its hammering or tappet beat, its cam and spring and half-speed shaft, being in universal use for all types of petrol, oil, and gas engines, both large and small. The gradual increase in the degree of compression during the last twenty years from 40 lbs. as used in engines of the slide-valve type, to upwards of 75 lbs., as used to-day in engines working with town gas, from 120 to 150 lbs. for larger engines using producer and furnace gas and upwards to 550 lbs. per sq. in. for high-compression injection oil engines, has necessitated a valve capable of maintaining under everyday conditions a more perfect gas tight fit than could be obtained from either the old type of cylindrical, disc, or any other form of slide valve.

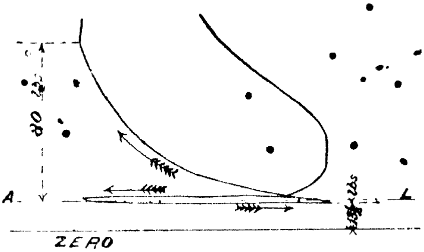
The superseding of flame ignition by the introduction of the incandescent tube in the ordinary gas engine no doubt considerably influenced the abandonment of the slide valve. Then, again, the slide valve was never found suitable as an exhaust valve, except in engines of very small size, and as a consequence of this one poppet at least was found necessary for each cylinder, and it only remained to further utilise the half-speed shaft by providing a second poppet for the admission of the charge, and to duplicate the cam, lever, and spring in order to dispense with the slide form of valve altogether, for

the ignition a third smaller lift valve was provided to control the timing of the charge contact with the incandescent tube.

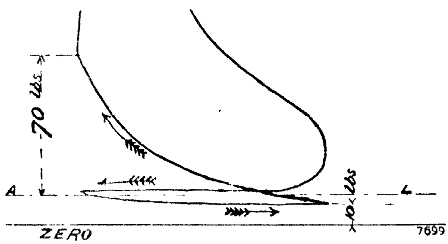
The modern tendency is always towards the attainment of higher power and speed from an engine with a cylinder of a given size, so much has the power efficiency increased in high-speed motors of the automobile class, that a motor of to-day is capable of developing considerably more than twice the power that could be obtained from one with the same bore and stroke ten years ago. Properly timed ignition and the supply of properly carburetted explosive mixture has had much effect in making this improvement possible. Another and equally important factor is explainable from the increased lung power afforded by correctly timed and perfectly gas-tight valves of large area, thus permitting higher speeds and working pressure, with a proportionate reduction in loss of power from the negative pressure of the exhaust and suction strokes.

In all engines the power efficiency of a cylinder of a given size is much reduced by wire-drawing or throttling the explosive mixture supply on the admission strokes of the engine, this effect is graphically illustrated by the induction, compression, and exhaust stroke diagrams (fig. 113), which show clearly the increased power efficiency that can be obtained by reducing negative resistance on the suction line. This improved working effect can only be obtained by using large inlet valves giving a very free opening, and by having all the branch pipes for the air, gas, and mixture supplies arranged to oppose a minimum resistance. These particular diagrams illustrating this effect were taken from an engine having a combined admission and exhaust balanced action rotary valve, with portways for the admission and exhaust of such size as to limit the mean velocity of the ingoing and outgoing gases past the portways in the valve or seat to a maximum of from 90 to 100 ft. per second, corresponding to a piston speed of 13 to 14 ft. per second. The pipes used to conduct air or mixture to the cylinder, and the exhaust to the atmosphere should be large enough to limit the velocity of inflow or outflow to within 80 ft. per second, and no unnecessary bends should be used. It is also important to use a regulator of correct design so as to afford a free gas-way when full open, provided

the engine is arranged to be controlled by varying the volume of mixture supply, as now most generally adopted in all engines of the high-speed class, also in many gas engines of large size, which are invariably provided with free opening



Scale, in. Piston speed, 800 ft. per minute.
Showing admission, compression, and exhaust lines on four-stroke engine running with throttle full open.



Scale, in. Piston speed, 800 ft. per minute.
Showing admission, compression, and exhaust lines with engine running slightly throttled.

FIG. 113.

variable cut-off valves in order to minimise the resistance of mixture flow to the cylinder to a fine point.

Referring to the two diagrams (fig. 113), the first shows a suction resistance of slightly over 1 lb per sq. in. and gives a compression pressure of 80 lbs., and on looking at the second diagram it will be seen that it corresponds very closely to a fairly good gas, oil, or petrol engine of the cam-operated poppet-valve type running at full load and speed. The suction line

in this case is 10 lbs. above absolute pressure, *i.e.* it indicates a negative resistance of some 4 lbs. per sq. in., and results in obtaining 10 lbs. less compression pressure than in the other case, also with a correspondingly reduced weight of charge drawn into the cylinder. There is thus a discrepancy shown of nearly 15 per cent. in the power value of these two diagrams, it does not, therefore, follow that an engine is by this amount more efficient from the point of view of fuel consumption, but is only so in its power output capacity. The point is, however, that an engine with a larger valve and freer opening is capable of a higher power duty, and this counts for so much in aero and other high-speed motors.

The piston speed in both these cases was identical, *i.e.* 800 ft., or thereabouts, per minute, and it will be seen that an engine provided with valves capable of giving a diagram with a minimum practical resistance, as shown by the first of these diagrams, would be well capable of being accelerated to a piston speed of 1000 ft. per minute or more, with less loss of efficiency than would result in an engine fitted with valves proportional to a diagram with the 70 lbs. compression, for instance. At slower speeds, below 500 ft. per minute, there would not be any appreciable difference in the running of the two engines, and, on the other hand, the higher the speed above normal the more is the power efficiency of the engine influenced by the correct working and large opening of the valves, which are veritably the lungs of the engine.

At this point it will be interesting to note the valve diameters required to keep down the velocity of the inflow or outflow to within 100 ft. per second, the valve and cylinder diameters in all cases, presuming piston speeds of 840 ft. per minute, thus corresponding to 14 ft. per second. The diameter of the admission valves may be taken at about 5 per cent. less than the sizes given, and the exhaust valves at 5 per cent. larger, in order to compensate for the difference in volume of the contents of the cylinder at the end of the charging stroke, as compared with the volume of gases to be exhausted after pressure release, the admission charge is taken as about 13½ lbs. absolute, and the exhaust 15½ lbs. These proportions apply more particularly to stationary engines limited to moderate speeds, but for auto-

mobile and aero motors with piston speeds exceeding 1000 ft. per minute, the opening can attain to one-fifth the piston area with advantage.

TABLE OF VALVE AND CYLINDER DIAMETERS.

Diameter of Cylinder.	Diameter of Valves	Diameter of Cylinder	Diameter of Valves.
3 in	$1\frac{1}{2}$ in	15 in.	$5\frac{1}{4}$ in.
$3\frac{1}{2}$ "	$1\frac{5}{16}$ "	18 "	$6\frac{3}{4}$ "
4	$1\frac{5}{8}$ "	21 "	8 "
5 "	$1\frac{7}{8}$ "	24 "	9 "
6 "	$2\frac{1}{4}$ "	27 "	$10\frac{1}{4}$ "
7 "	$2\frac{5}{8}$ "	30 "	$11\frac{3}{8}$ "
8 "	3 "	33 "	$12\frac{3}{4}$ "
9 "	$3\frac{1}{2}$ "	36 "	$13\frac{1}{2}$ "
10 "	$3\frac{3}{4}$ "	42 "	16 "
11 "	$4\frac{1}{2}$ "	48 "	18 "
12 "	$4\frac{3}{4}$ "	54 "	20 "

Much attention has been centred on minimising the fluid resistance caused by the suction and exhaust strokes of high-speed engines, and provided this can be reduced to a negligible quantity, there will remain no reason except the mechanical balancing of the moving parts to prevent piston speeds of considerably over 1000 ft. per minute with maximum efficiency. With this end in view engines have been constructed with a variety of different forms of valves, as will be shown later, the admission of the charge in some cases can be controlled by double and treble poppet valves for each cylinder, and in others by annular and double-seated poppet valves, etc., and the exhaust by double-ported valves, and in the two-cycle engine by wide ports directly controlled by the motor piston, there are, besides, rotary, sleeve, liner, and other forms of valves, all having the purpose of a free gas-way combined with mechanical efficiency.

Water-cooled Exhaust Valves.—The exhaust valve is generally considered the most important part in a four-stroke engine of large size, it being necessary to always water-cool the seat and the valve itself in engines with cylinders exceeding 20-in. diam. It is also thought by many makers advisable to

balance the force required to open the valve against the pressure in the cylinder at the end of the power stroke. The wear on the operating mechanism is very considerable unless some means, either of reducing the resistance opposed to the valve or of giving it a preliminary small degree of lift so as to release the cylinder pressure, is adopted. For instance, in the case of a cylinder of 43-in. diam having an exhaust valve of 14 in. diam. the pressure opposed to the valve's lift is over three tons. However, in many engines of large power no balancing action is provided, and the actuating mechanism is relied on entirely for opening the valve against the full terminal pressure. In the Dingler gas engine (fig 114), with a cylinder of 25-in. diam a simple water-cooled casing, B, is used from which the circulating water is further utilised to cool an unbalanced valve, V, by causing it to flow up the hollow stem, D, returning by an inner tube, T. In the Dunlop (fig. 115) the valve, V, is shown cast in one piece with a balancing piston, which makes a gas-tight fit in a cylinder bored in the cover, R. This valve is hollow, and controlled by a stem passing up through the water space to the cam lever, M. Water from the cylinder jacket is forced into the nozzle over the valve, and thence flows down the inside of the valve and balancing piston, leaving the exhaust passage by the nozzle, Z. The valve thus serves for the water overflow, and is kept at almost the same temperature as the water itself. One drawback is that the water, in flowing round and over the valve piston head, prevents lubrication of the rings, and is liable to leak into the cylinder

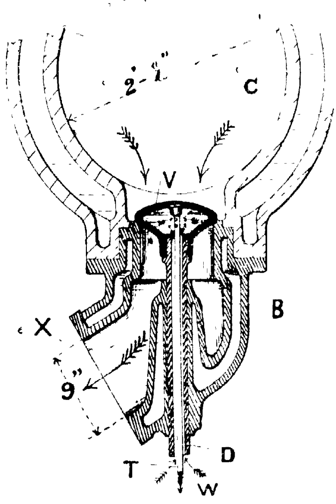


FIG 114.—Dingler water-cooled exhaust valve.

under certain conditions, but the chief objection is the liability to rusting of the valve piston, rings, and cylinder.

In one form of Crossley balanced exhaust valve, shown in fig. 116, the valve, V. is cast in one piece with a balancing piston forming, as it were, an enlarged valve stem, N. This stem piston is of equal area with the valve, V, and fits gas-tight in a cylinder bored out of the valve casing. Communicating with the under side of this piston, N, is a portway, R, which opens to the under side of a small pilot valve, P. Just before the time for opening the main valve, V, the pilot valve is opened by the cam lever, M, which action places both ends of the large valve in equilibrium; the valve can then be easily raised off its seat by the cam stem lever, K, and stem, T. In order to circulate water through the interior of the valve and balancing piston the end of the stem, T, fits in a water case, which is connected to the inlet for water at W and outlet at the bottom, the supply passing up the stem and returning by the inner tube in the usual way. The valve, which is held down on to its seat by the tension spring, G, is always kept full of water, and is thus prevented from overheating.

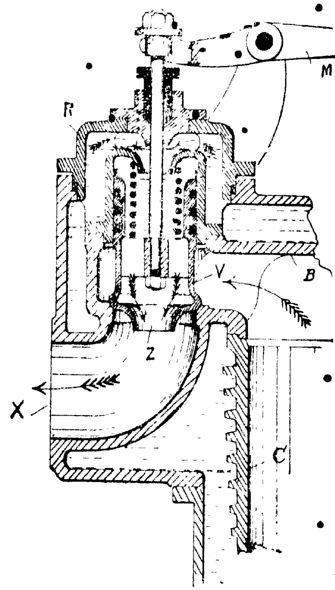


Fig. 115.—Dunlop water-cooled balanced exhaust valve.

Fig. 117 shows a section of a type of balanced exhaust valve of ordinary construction, adopted in certain large-power engines of British manufacture. This is, perhaps, the simplest form of balanced valve, and has the merit of requiring no

cover, the balancing piston, P, taking its place. The valve, T, is cast as before in one piece, with a piston head, P, held down by a pression spring under simple adjustment from the crosshead placed over it. The valve is screwed on to a steel stem, D, which fits water-tight in the gland case, G, supplied with water at W, whence it flows up the stem, D, and around the inner tube, E, by which it returns to the outlet union nut at the under side of the case, G. All that is necessary in order to remove this form of valve is to slack back the cam collar on its stem and take off the spring head, when the valve is free to be taken out without breaking any joint. Another point in its favour is the free accessibility of the piston-balancing head for lubrication and detection of leakage.

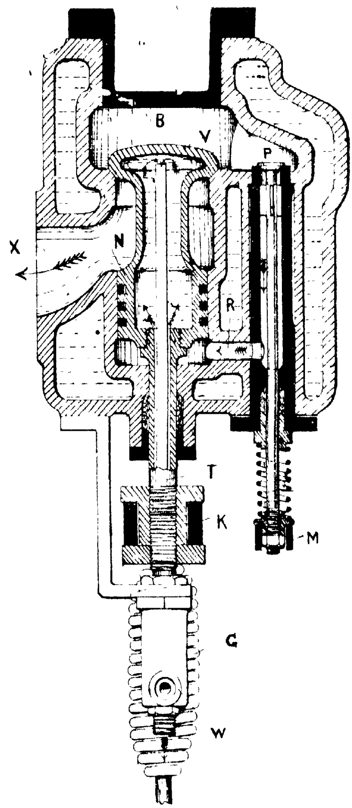


FIG. 116.—Crossley water-cooled exhaust valve with balancing piston and pilot valve.

The largest exhaust valve illustrated is the Otto-Deutz balanced-action double-seated poppet, shown by the section at fig. 118. This valve, as is usual in Continental practice, is arranged on the under side of a horizontal cylinder, C. The valve seat, L, forms a separate casting, and is independently water-cooled to the casing, A, which is in turn

bolted to the cylinder jacket, and carries the exhaust pipe of 14-in. diam at X. The casting forming the valve seat and guide is held up to the cylinder—a gas-tight fit by spring washers and bolts to allow for any difference of expansion The valve itself is cast hollow, and is provided with a balancing seat at S, by which the valve, V, is placed in a state of equilibrium by the passage, B It will be seen that although the valve is fitted with a double seat, only one of these serves for the exhaust of the gases, the under seat being simply used to give a balancing effect The valve is placed under the cylinder, so that accumulation of dust from the gases may be prevented, and by the construction, which is self-explanatory, the exhaust gases are permitted an exceedingly free escape, and are surrounded on all sides by water-cooled walls. The stem is screwed into the poppet head in the usual way, and fits in a water case at bottom provided with a gland leakage tray, Y, for running off escape of water.

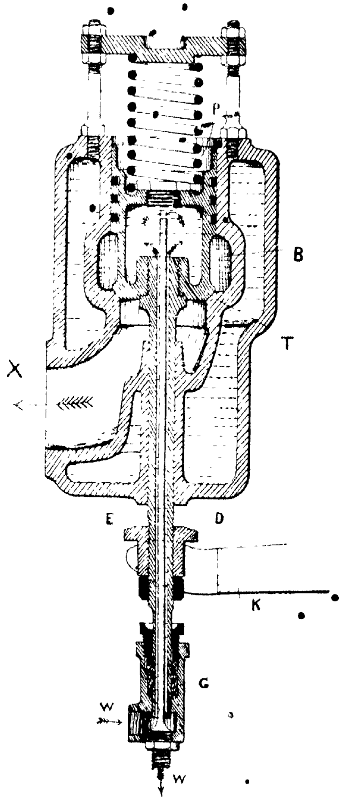


FIG. 117.—Open type of balanced action water-cooled exhaust poppet piston.

Cooling water to the valve is carried up the stem, and returns by an inner tube, where it enters at the highest point under the valve crown, the space around the tube being in connection with the water service pipes, W. In order to prevent leakage

of exhaust gases caused by any slack around the valve stem and the central guide bearing, this is provided with packing rings and a supplementary asbestos packing box held up by the valve spring. The cam lever, K, lifts the valve by a crosshead provided with a pin at each side, into which are fitted friction rollers for engagement with the lever fork end. The crosshead fits on the valve stem against a shoulder and permits the ready removal of the valve up through the combustion chamber and out by the opening at the top provided for the inlet valve. In this manner only one pressure joint is broken to remove both the admission and exhaust valves, and readjustment of the connections between the exhaust valve and operating mechanism is avoided.

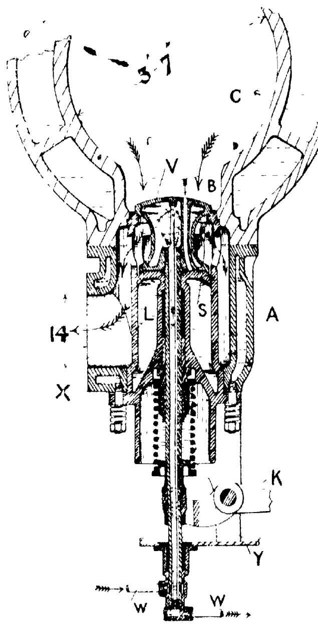


FIG. 118.—Otto-Deutz water-cooled and balanced exhaust valve.

It will be noted that the exhaust valves shown in each of the preceding examples have detachable seats, and that the valves in each case are also located under the combustion chamber, it being the usual practice in the larger engines to construct the valve casing as shown in figs. 126 to 130, which represent some of the most carefully thought-out examples of this kind. In the latter example the valve is, of course, water-cooled, but the water enters the crown of the valve in a manner differing from usual practice. Referring to the illustration (fig. 130), it will be seen that water enters at W in the conical guide chamber, K, whence it flows through openings in the stem, M, and thence

into the inner tube, T, escaping just under the crown of the valve at V: the water now returns between the tube, T, and stem, M, to the jacket, A, of the valve-seat chamber, C, whence it circulates by the tube, P, to the jacket space, C, and outlet, O, the jacket in the outer casing containing the exhaust outlet, E, being supplied by a separate pipe, not shown. The valve seat is separately jointed to the under side of the combustion chamber, the space below the valve communicating by four radial passages, D, with the expansion chamber, X, whence the exhaust escapes at E through a pipe, which in some cases is also jacketed. To remove the valve all that is necessary is to slack back the set-screws, S, when the valve with its stem, M, can be drawn up through the opening in the top of the combustion chamber without disturbing the spring within the plunger, G, the latter being removed if necessary from the socket fitting over the bottom of the valvestem by unscrewing the retaining nut, U. The circulating tube, T, not requiring to be open at the bottom, is secured direct to the outer stem, from which the valve itself can be removed by slacking back the set-screws shown: in this manner either the valve or its stem can be separately renewed. Other water-cooled exhaust valves and combined admission-exhaust valves are shown in figs. 123, 124, 125, 125A, 129, 130.

CHAPTER VIII.

ADMISSION VALVES; COMBINED ADMISSION AND EXHAUST VALVES; VALVE ARRANGEMENTS AND ACTUATING GEARS, FOR GAS AND OIL ENGINES.

Admission Valves.—In large-power engines using producer and similar gases the admixture of gas and air is conveniently effected by special forms of admission valve, which are for this purpose provided with an annular passage or with a ported piston on its stem. In some cases the piston valve and poppet are actuated by independent mechanism the ported piston, for instance, in some cases being given a trip cut off action by which the supply of gas is controlled independently of the air by the governor In the Cockeril admission valve there are two seats, of which one is exposed to the cylinder pressure . gas is supplied at G (see fig 129) and air at A, which enters the cylinder in an annular stream surrounding a central column of gas. The admission valve is arranged contrary to usual practice at the bottom of the cylinder alongside the exhaust valve, and is given a cut-off motion by an eccentric trip-gear, the supply of gas is usually independently controlled by a throttle valve.

In the Premier engine the supply of gas is controlled by a ported piston; by this means the admission of gas is entirely independent of the air supply In one position the air ports are open to the air passage, this permits of the valve being opened for a full supply of air for flushing purposes, or in case of a cut-out charge by the governor. It is important in engines using producer gas, and even more so with furnace gas, for the valve to be capable of supplying a full air-charge without throttling action when the supply of gas is either com-

pletely or only partially cut off owing to the large proportion of gas used to form an explosive mixture.

In the admission valve for large-power two-stroke engines which is arranged on the cylinder top, there is only one seat exposed to cylinder pressure both gas and air are, however, supplied by separate charging pumps, air entering in an annular column with the gas charge down the centre. The valve is usually operated by a lever spring and eccentric on a side shaft. By an arrangement of valves on the charging pumps, immediately after the release of the exhaust pressure by the motor piston, an air charge is first driven in which clears the cylinder of burnt gases and escapes by the zone of exhaust ports around the cylinder, as shown in the diagrammatic section fig. 142. In this period the motor piston advances and closes the ports, when the gas and air charge is forced in without incurring any loss by escaping with the exhaust.

As before described, the method adopted for the admission of the charge of gas and air in the double piston two-stroke type of engine (*vide* Chapter IX.) is by ports controlled by one of the motor pistons, no valve whatever being required on the power cylinder. The charge is supplied by separate air and gas pumps arranged to clear out the cylinder by an air charge in advance of the mixture supply of gas and air. In order to prevent loss of power from a throttled governing supply of gas, or gas and air, to the charging pumps in large engines of the two-stroke class, the pumps are always allowed to work on full supply, the delivery to the power cylinder depending on a governor-controlled bye-pass between the delivery and suction pipes.

Combined Admission and Exhaust Valves.—The construction of a successful combined admission and exhaust valve for large-power engines has engaged the attention of many engineers, the aim in all cases being simplicity and efficiency in the design and working of the engine. One of the earliest of these combination valves is the Fielding, illustrated in fig. 119. In this the pressure poppet, V, is provided with a hollow piston or poppet, P, shown in position for admitting the charge of gas and air from the inlet passage, A, which passes up through the valve and into the combustion chamber under the valve, V.

The hollow poppet is closed to the exhaust outlet, X, being held up to a seat in the exhaust chamber by the spring, G. During the exhaust stroke of the power piston the pressure valve V is raised to an intermediate position, when the neck of the hollow poppet below is closed by the valve, V, the hollow poppet in this position is thus depressed off the seat below the neck, so opening communication from the power cylinder to the exhaust outlet. This form of valve requires a two-stage lift as shown in dotted lines, and should be a free sliding, yet gas-tight fit between the intake and exhaust chambers. It however has some faults, one a constricted admission area past the neck of the distributor, P, another the high lift of the pressure valve, V, causing considerable pounding of the seat and noise but the worst is the frequency of back fires due to leakage past the shoulder, thus allowing hot gases to mix with the ingoing charge.

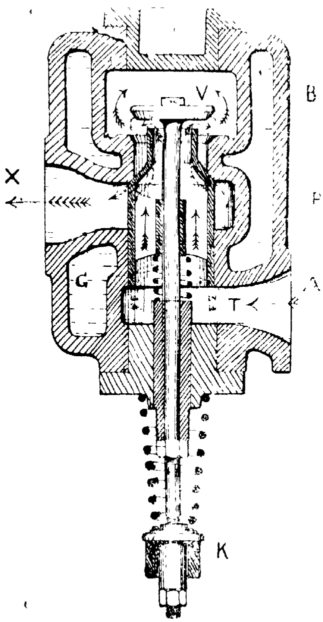


FIG. 119.—Fielding combination valve.

A properly designed combination admission-exhaust valve has two advantages, one the possibility of a greater gas-way area with reduced resistance to the ingoing and outgoing gases, another the lower temperature of the valve due to the ingoing charge, consequently there is less wear than obtaining in an ordinary exhaust valve, there is, moreover, with a combination valve, the same advantage in reduced pocket area as in a design where the inlet valve is placed over the exhaust. In the example, fig. 120 (adapted more particularly for a vertical

engine), the two stems are separately operated by cam levers or push-rods, v^1, e^1. In this design the pressure valve, v, only requires a normal lift. Leakage of exhaust from x, past the hollow piston, e, when pushed up into the recess, r, is minimised, and can be entirely prevented by arranging for the outer edge of e to press against a seat in the recess, r, the piston, e, in such case being preferably of larger diameter, so as to afford a free way for the exhaust. There is no possibility in any case for exhaust gases to be blown past the piston e, and thus mix with the mixture supply at s which is important. This design lends itself either to a cut-out, hit-or-miss governor control or to the use of a throttled mixture supply, and is accordingly adapted for high-speed engines of the multiple-cylinder type. A valve of this design moreover, lends itself without material modification to the cylinder head, where, in common with other forms of combination and annular seated valves, such as shown in figs. 154 to 158, for instance, it has a maximum advantage over the usual separate valves for admission and exhaust, a valve of this type is peculiarly adapted for four-stroke high-compression oil engines, for, as only too well known, the placing of the necessary admission, exhaust, injection, and starting valves in the restricted area of the cylinder cover of such engines presents the greatest difficulty in their design.

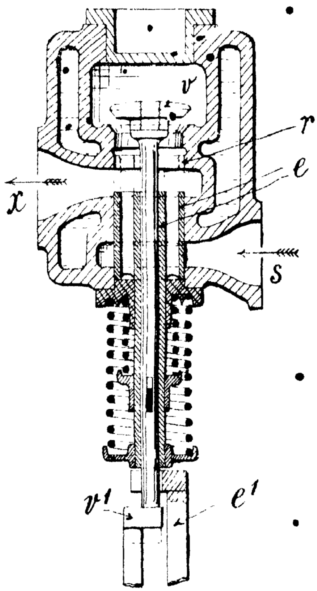


FIG. 120.—Modified form of combined admission-exhaust valve with separately operated distributor sleeve—Butler.

The use of a piston or sleeve under the pressure valve not

only simplifies the operating gear, but reduces the clearance, which is important in a gas engine thus avoiding waste of mixture on one stroke and contamination on the other. However, a triple poppet combination admission-exhaust single-pressure valve gear, as shown in fig 121, has been used on a comparatively large engine, known as the De Boutville, a 100-h p. single-cylinder gas engine so fitted having been shown at the Paris Exhibition of 1889 In this design an ordinary pressure poppet, V, opens into a pocket, B, at the side of the cylinder, the admission and exhaust to the under side being controlled by two cam-operated poppets, N T, one being open during the exhaust stroke, and the other during the admission stroke The three valves are arranged in line, and are equally accessible During the admission stroke the valve, T, is closed and the valve, N, opened, and during the exhaust stroke their action is reversed. It will be seen that this combination is neat, and has only one valve exposed to cylinder pressure and as this valve acts as an admission valve, it is cooled to a considerable extent, and has been used for a cylinder of 18-in. to 20-in diam without having to be water-cooled. The drawback to this arrangement is the large space under the valve, V consequently the contents are wasted at each exhaust stroke unless the gas valve is closed in advance of the air valve Gas admission is also delayed to avoid back-firing

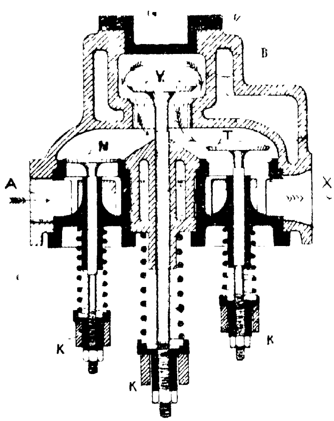


FIG. 121 De Boutville combination valve

In the combination valve shown in fig. 122 (Fielding's) a pair of valves are arranged one over the other, the upper valve serving as an admission valve and also to balance the exhaust valve. This combination is very ingenious, simple, and acces-

sible, but has two seats exposed to the cylinder pressure. In action the cam lever, M, lifts both valves during the exhaust stroke, when, during the admission stroke, the valve, T, will be closed by its spring, and the valve, N, held up by the cam lever, K, for the passage of gas mixture from A to the combustion chamber, B, *via* the hollow piston extension of the valve, N which is provided with packing rings, as in the case of the balanced exhaust valves shown in figs. 115 and 117. This valve in common with others of the combination type, has the advantage of being cooled by the inrush of the gas mixture.

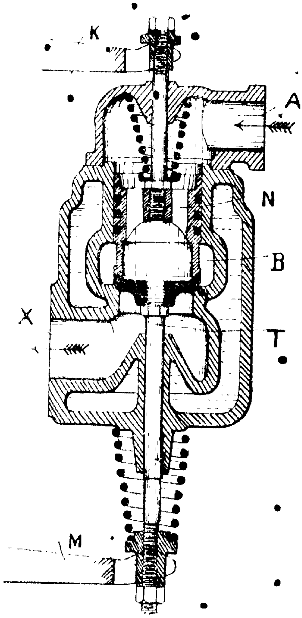


FIG. 122.—Combined admission and exhaust valve with balancing action Fielding.

The balanced valve fig. 123 has been designed for larger engines and is water-cooled. In this example the exhaust valve T, is cast together with a balancing piston head in the usual way, but instead of this piston fitting in a cylinder formed in the valve case, as in fig. 117, the head of the exhaust valve fits gas-tight in the cylindrical admission valve, N, the space between the head of the valve, N, and the bottom of the piston, P, being utilised for enclosing a long spring which serves to keep both the admission and the exhaust valves on their seats. A detachable cover is used to guide the admission poppet, N, and to serve as its seat. Both valves are water-cooled and balanced against cylinder pressure or suction by the telescopic action shown, and are independently opened by the two cam levers, K and M. Cooling water enters by gravity from the small service pipe, W, and maintains both the

stem and piston head of the exhaust valve always full of water, the overflow escaping by the central tube to the outlet nozzle at W, and as will be seen, both the inlet and outlet streams of cooling water are exposed to observation thus providing against accidental stopping of the supply, any shortage of water forewarning the attendant by the visible escape of steam, a considerable time before attaining the danger point of overheating. There is only one spring required, and the two valves can be removed, either singly or together. The water-cooled combined admission-exhaust poppet valve shown in fig. 123 is more suitable for large-power engines, and in common with the combination admission-exhaust poppet shown in fig 122 is entirely balanced against cylinder pressure.

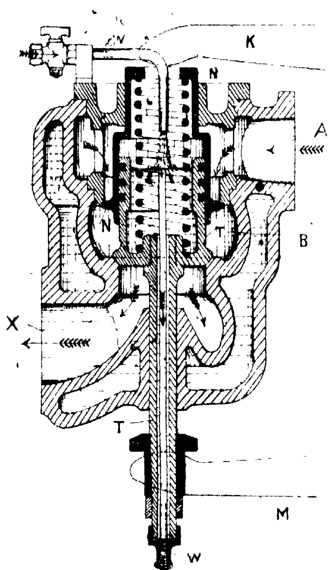


FIG. 123 Water-cooled combination valve - Butler.

In order to provide a very large area of valve opening, approaching to well over one-seventh the area of the power piston, the double-seated balanced combined admission and exhaust poppet valve, fig. 124, has also been designed by the writer In this valve there are two seats, communicating with portways, forming part of the combustion chamber, both the top and under sides of the double seated poppet are open to the cylinder by the portways, U. The pressure valve, V, is held open during both the admission and exhaust strokes by the push-rod, K, this particular arrangement being designed for a vertical engine The inlet and outlet of mixture and exhaust

are controlled by the piston valve T, which is actuated by an eccentric and rod D on the half-speed cam shaft. In the position shown, both valves are open for the admission of gas mixture from the inlet at A and through the port openings in the liner for the piston, T, to the space, E communicating to both

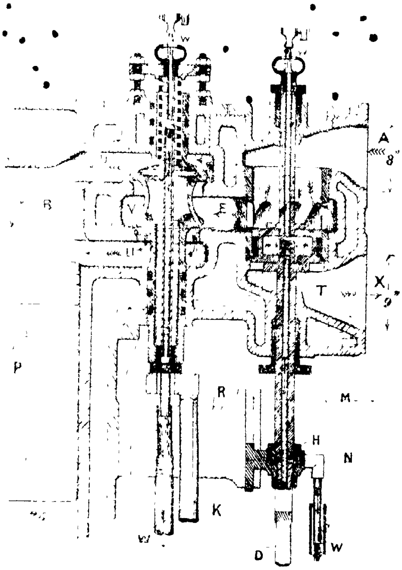


FIG. 124 Design for a water cooled double-seated balanced-action combined admission and exhaust valve for a 24-in vertical gas engine Butler

seats of the pressure valve, V, and thence by the two passages, U, to the combustion chamber, B During the exhaust and admission strokes the double-seated poppet, V, is retained in the open position as shown, and the necessary distribution from exhaust to admission is effected by the piston valve, T, which is moved to a position shown by the dotted line, M, when the cylinder is placed open to the outlet at X. Both poppet and piston are water-cooled by a gravity feed as in fig. 123, the water entering by a visible stream feed and escaping into the

drain pipes, W. The pressure valve, V, is cast in one piece with a hollow stem at each end, which are both provided with packing rings, and is readily accessible and easily removed for examination at any time without having to interfere with the actuating mechanism in any way, the retaining spring being held down under compression by the cover over the valve; this construction also simplifies the general appearance of the engine. The same method of cooling is adopted as in the preceding design, by which the valve is always kept full of water, there being no glands used or possibility for leakage, and in this way the risk of running the engine for such a time as may cause overheating by failing to turn on the water supply, or through accidental stoppage in the circulation, is entirely avoided, the valve being at all times full to overflowing, and so arranged as to give timely warning of an insufficient supply.

The principal advantage obtaining from the use of a combination valve is, undoubtedly, that only one, the poppet, is exposed to cylinder pressure; also that the valve has only one beat for the double stroke, and as the contact area is cooled by the ingoing gases, this gives a further advantage. In order to obtain the full benefit from a combination valve a separate gas-controlling valve should be used so that the supply may be cut off before the completion of the induction stroke, and by this means burning of explosive mixture in the space intervening between the pressure valve and the distributing valve is avoided. In the design shown in fig. 121, for instance, the space below V and over N and T should be emptied of explosive mixture before the valves, V and T, are opened for the exhaust, as any explosive mixture contained in this space will be wasted during the exhaust stroke. This clearance in the double-ported valve (fig. 124) is reduced by the use of the piston distributor, T. It is advisable, however, in this case to cut off the gas before the termination of the charging stroke of the motor piston, P, to eliminate any possibility of back-firing, and for reasons of economy.

The combination valves as illustrated in figs. 122 and 123 have the advantage of being balanced against the terminal pressure in the cylinder, but have two seats, and, from this point of view are identical in working with two separate valves

arranged one over the other. The combination valve shown in fig. 122, owing to being covered by the inlet balancing piston, N, is protected to a great extent from the heat of the explosions, and is found to work well with cylinder diameters of 15-in. downwards, the stem of the exhaust valve, T, may also be made hollow so as to permit of the admission piston valve, N, being actuated by a rod passing up through the bottom valve with an arrangement of push rods as shown in fig. 120. In the combination valve (fig. 123) the water cooled exhaust poppet, T, is fitted with a balancing piston head as shown in fig. 117, but in this case the cylindrical guide, N, is utilised for mixture admission, and the combination valve being water-cooled, is suitable for engines of large size.

The advantage gained in using two valves is more obvious in the case of large cylinder diameters than in small motors owing to the ratio of valve lift not keeping pace with the increase in diameter. The sizes given in the table of valve and cylinder diameters (p. 183) however are taken from the usual allowance of a lift of one-quarter the valve diameter at the bottom of the seat, this ratio of lift to diameter giving approximately an equal opening to the valve area after allowing for the space taken up by the valve stem. Referring back to the table of sizes, a valve $1\frac{1}{2}$-in. diam. is allowed for a cylinder of 4-in. diam., the lift in this case will be $\frac{3}{8}$-in., to give the full opening to the valve. Now, advancing to an 8-in. diam. cylinder having a 3-in. diam. valve the lift should be $\frac{3}{4}$-in. to obtain the maximum useful opening, in practice a lift probably not exceeding $\frac{5}{8}$-in. would be allowed. Again, in taking, for example, a still larger cylinder of, say, 24-in. diam. having a valve 8-in. diam., the lift should be 2-in. to obtain the full opening capacity of the valve. It is doubtful, however, if an engine of this size, especially if constructed to run at a high speed, would have a valve lift greater than $1\frac{1}{4}$-in. to $1\frac{1}{2}$-in., accordingly it will be seen that there really is a good reason for using two valves to take the place of one in engines of large size. For instance, in an engine of the size last given, viz., with a cylinder diameter of 24-in. a single valve of 8-in. diam. with a lift of $1\frac{1}{2}$-in. would give an opening of about $37\frac{1}{2}$-in. area, whereas the full capacity of the valve itself is more nearly $47\frac{1}{2}$-in. area. Now, assuming that

either one double-seated valve or two ordinary single-seated valves are used, which afford in either case approximately an equal area it will be found that 5¾-in diam. and 1¼-in. lift with a double valve will afford a gas-way opening of 45-in as against 37½-in as in the case of a single valve of 8-in diam, the areas of two 5¾ in. diam valves being equal to one valve of 8-in. diam.

Some makers take advantage of this practice and use two exhaust valves in place of one A further advantage gained by the duplicated valve is that one of them may have sufficient lead in advance of the other to release the pressure in the cylinder before the opening of the second valve, by which means the resistance opposed to the opening of the valves is reduced by nearly a half and to some extent minimises the necessity for using a balancing piston head to the exhaust valve The cost of a double valve as illustrated in fig. 124 is less than two separate valves of equal diameter, each provided with an independent cam and lever. The double-seated valve is, moreover, entirely balanced, and if arranged with some form of admission-exhaust distributing valve, which may either take the form of a concentric piston or be combined with a separate poppet- or piston-valve control, it is possible to obtain a very free gas-way with a minimum of surface exposed to heated gases under pressure

It has been pointed out to the writer that a double-seated valve does not lend itself for being located at the bottom of the combustion chamber, which is the prevailing practice in large-power horizontal engines run on blast-furnace gas, to prevent accumulation of dust and flume. This objection, however, only holds in degree, and has been got over as shown in fig. 118, but in this form it loses the advantage of a double opening, although retaining a balanced action Both double opening and balanced action can be obtained in a horizontal engine by arranging the exhaust water-cooled double-seated poppet, *e*, horizontally underneath the cylinder head, and the admission valve, *a* on the top in the usual manner, as shown in fig. 125. In this design the valve is really in a more get-at-able position than an ordinary single-seated vertical lift valve located under the combustion chamber of a horizontal engine, as when arranged

in this manner the valve can be taken out after simply removing the cover, and without interfering with the operating gear *e*. The advantage of this will be obvious to anyone having experi-

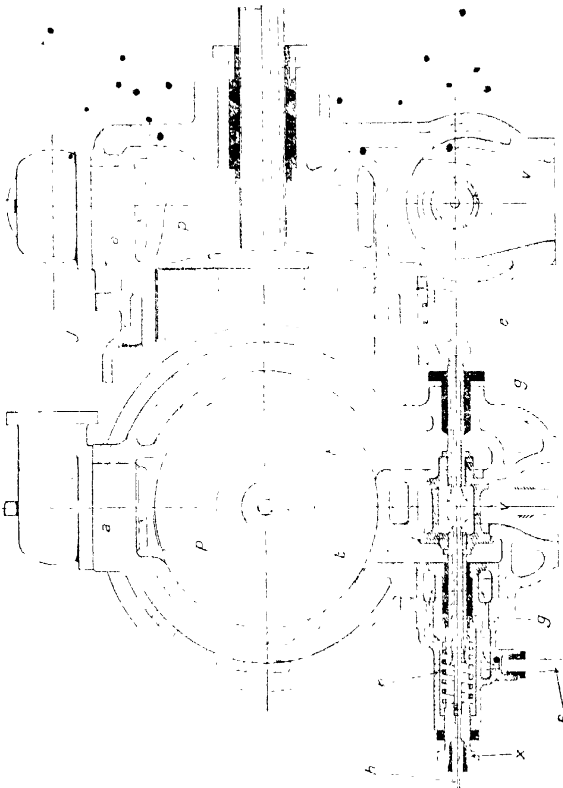


FIG. 125.—Sectional elevations of cylinder head of 24-in. double-acting blast-furnace gas engine, showing double-seated balanced-action water-cooled exhaust valve arranged horizontally.—Butler.

ence of this work. The valve is well supported at both ends by hollow water-cooled stem connections carried by metal ring-packed gas-tight bearings, *g*, the packing and adjustment of which are conveniently accessible; this latter remark also applies to the comparatively small and enclosed valve spring, *n*,

and again to the circulating water inlet and outlet connections, h, j. In fig. 125A a double-seated exhaust valve of similar form is shown arranged at the side of a horizontal cylinder, here the inlet valve, a', is located over the balanced exhaust poppet, e', which has only one stem, but in this design, although the valve can be drawn through the opening for the air-valve casing it is necessary to remove the collar engaging with the operating lever e' as in ordinary practice but as an offset to this, there is only one gland-packed bearing, g', and one connection, h', for the cooling water. In regard to the superiority of one over the other of these two designs, it may be advanced that the horizontal valve is more advantageous in engines of large size, and the vertical to smaller engines of horizontal form. Any difficulty that may arise, due to unequal expansion of the valve and the double seating, will probably be found very slight, as the surface on all sides of the double port connections, t, t, is water cooled; besides, the length of the valve is only one diameter, and the working conditions, although widely

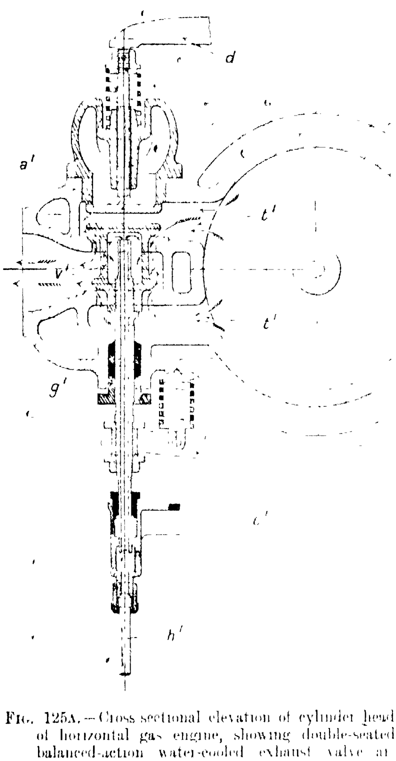


FIG. 125A.—Cross sectional elevation of cylinder head of horizontal gas engine, showing double-seated balanced-action water-cooled exhaust valve arranged vertically.—Butler.

different from that obtained with steam, yet favour the promise that ultimately these will not be found so dissimilar as to prevent its obvious advantages being realised.

Valve Arrangements and Actuating Gears.—The distributing valves in both gas and oil engines of the horizontal type are

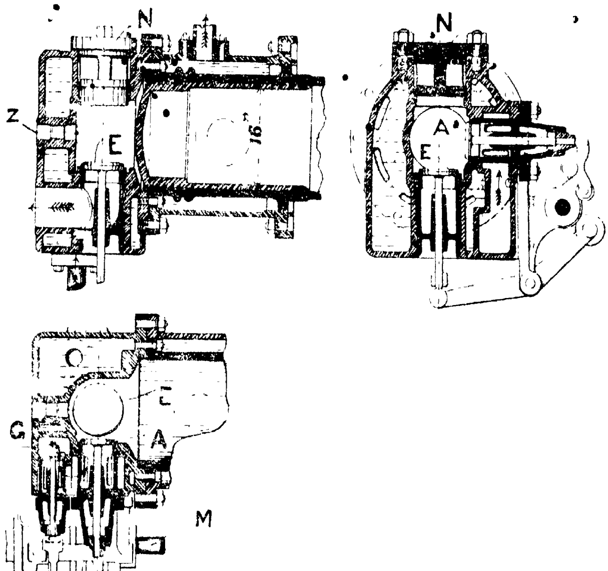


FIG. 126.—Disposition of gas, admission and exhaust valves in Paxman horizontal gas engine, showing also typical arrangement of side shaft cam-actuating gear.

invariably actuated by a cam shaft arranged alongside the cylinder at a point below the centre line of the crank shaft, and it is now the universal practice to communicate motion to the cam shaft by a pair of skew wheels, gearing in a ratio of 2 to 1. A typical illustration showing the usual disposition of the valve shaft, cams, exhaust, admission and gas valves is seen in fig. 126, the exhaust valve, E, being located at the bottom of the combustion chamber and having a cover, N, for its removal,

which in this case is made in the form of a compression plug, by which means the degree of compression may be adjusted to give a pressure of, *e.g.* 80 lbs. per sq. in., when it is desired to work on town gas, and with a deeper plug to obtain a pressure of 100 lbs. or more for use with producer gas. A separate valve seat, as shown, is not always used for the exhaust valve, the more usual practice being as shown in fig. 127, with the admission

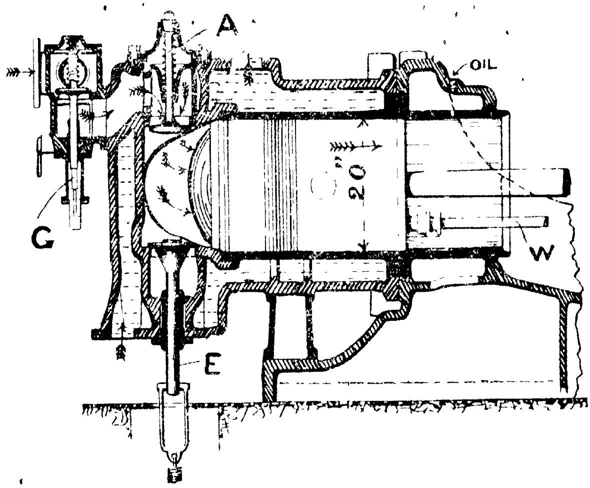


FIG. 127.—Sectional view of Tangye gas engine, showing disposition of gas, admission and exhaust valves.

valve directly over it, for engines of the single-cylinder type of moderate size. The exhaust valve, again, is often placed at the side of the combustion chamber remote from the actuating shaft, an arrangement which involves the use of a longer lever and a breech end of a more bulky character. In the hundred or so makes of the ordinary single-cylinder horizontal gas engine, in most of which cam-actuated valves are used, there is an exhaust valve, admission valve, and—in engines governed on the hit-and-miss method—a third valve, also cam-actuated, this valve, shown at G, only being opened when a "working stroke is required. The engine with its charge of gas cut-off" thus works

with a throttling action, no supplementary air-supply being used to compensate for this, and the compression following a cut-out admission stroke in an engine working on producer gas will, on this account, fall from 100 lbs. to somewhere between 70 and 80 lbs. per sq. in. with a corresponding drag on the piston. Partly on this account, and to obtain an impulse at each working stroke, most engines of large power use either a throttle on the mixture supply or a cut-off gear, the admission in the latter case being controlled by a trip action, the closing of the valve depending on the governor, speed, and load. An example of this character is illustrated in fig. 129, the valves in this case being opened and closed by oscillating cams receiving their motion from eccentrics on a half-speed shaft. In the Dingler engine two cam shafts are used, one to determine the time of opening of the admission valve and the opening and closing of the exhaust valve, and the other for closing the admission valve. In the Nurnberg horizontal and the Rathbun vertical engines the valves are actuated from a side shaft and eccentrics, the admission valve being under the control of a governor trip action and the exhaust valve of a rolling cam gear, as shown by fig. 130, where the oscillating cam, R, receives its motion from an eccentric and lifts the valve, V, through the lever, L, and ball, B, the valve stem, M, being guided by the plunger, G, within which is neatly arranged the return action spring. By this form of actuating gear the exhaust valve on being opened receives at first a very slow movement, the opening immediately following the release of cylinder pressure being accelerated by reason of the rolling contact of R approaching the fulcrum of

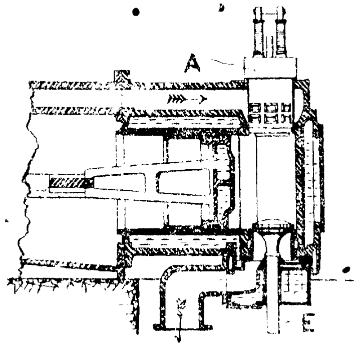


FIG. 128.—Sectional view of Premier gas engine, showing arrangement of admission and exhaust valves.

the rocker lever L. The curve of the actuating cam, as at M, is also formed to obtain an equivalent result as will be seen on reference to fig. 129, for the opening of the exhaust valve, as at E, for instance; the trip cam K, for mixture admission cut-off is provided with an air-cushion dash-pot, T to soften the closing action.

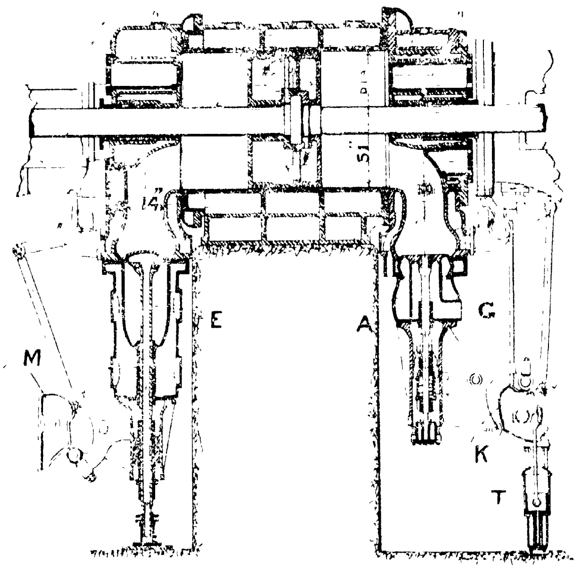


FIG. 129.—Sectional view of Richardson & Westgarth double-acting gas engine, showing arrangement of admission and exhaust valves, and oscillating cam-operating gears.

In regard to the diameter of valves, it will be seen that the exhaust valve in fig. 126 is one-third the diameter of the cylinder, in fig. 127 it is 0·36, in fig. 128, 0·4, in fig. 129, 0·34; and in fig. 130, 0·30, these proportions in all cases falling slightly below the figures given in the table in Chapter VII. This is to be accounted for by the desire to keep down the pressure resistance opposed to the actuating gear, the pressure on the exhaust valve at the moment of release in the engine

shown in fig. 129—which represents probably the largest cylinder yet made,—in many cases exceeding 50 lbs. per sq. in. This

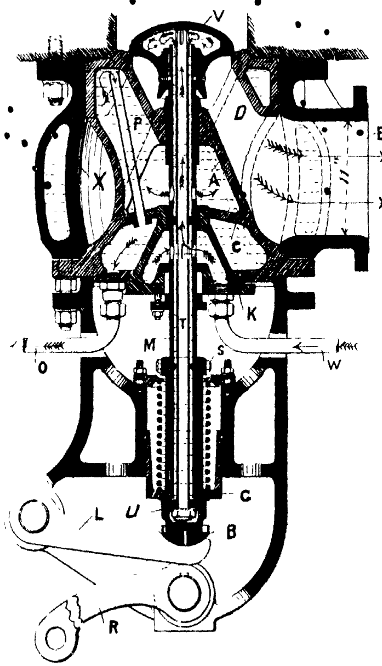


FIG. 130.—Water-cooled exhaust valve for 35-in. diam. Nurnberg gas engine with rolling cam and eccentric operating gear

points to the advantage of using an exhaust valve, constructed to be balanced or nearly so to the terminal pressure of the cylinder gases, in minimising strain and wear on the actuating gear.

CHAPTER IX.

ROTARY DISTRIBUTING VALVES; ENGINES WITH SINGLE- AND DOUBLE-PISTON CONTROLLED ADMISSION AND EXHAUST.

Rotary Valves.—The most effective substitute for the lift poppet valve is undoubtedly a thoroughly balanced form of self-adjusting rotary valve. Many such valves are in use, and give very satisfactory results. Any form of sliding valve whether it be reciprocating or rotative, must necessarily have a slow surface speed, and be relieved of the major portion of the pressure resulting from combustion of the compressed explosive mixture.[1] In the evolution of the internal combustion engine many forms of rotary, cylindrical, and disc valves have been used with varying degrees of success. A very good example of a disc valve is illustrated by the Raymond combined admission and exhaust valve (fig. 131), which represents a section of a cylinder used in a 100 h.p four-cylinder vertical gas engine made by Case & Co. of America. In order to reduce the surface friction in this engine a ball race was used, thus taking up the great pressure tending to force this large diameter disc against its seat on the cylinder cover. For the sake of clearness this detail is not shown in the illustration, the rolling path or race for the bearing balls is arranged in one design between the ports and the valve stem, and in another on a flange situated above the spur driving wheel. Referring to the illustration, C is the disc valve having duplicate admission and exhaust port openings, R R, which coincide with two pairs of portways, T T and N N, in the cylinder cover during each half revolution of the valve; there are thus duplicate admission and exhaust inlet and

[1] Reproduced from articles published in the *Engineering Review*.

outlet branch facets, A A and X X. The valve stem is hollow, and carried up through a bearing neck in the cylinder cover, where a spur wheel, S, partly supported in an independent bearing, is keyed to the valve stem D, by a sliding feather fit, thus permitting the valve to be held up by the spring, E, and is thus relieved of the weight of the driving wheel. In the top of the valve stem, D, there is a gland-packed intake for the circulating water, which enters by the regulating tap shown by way of the inner tube, this extending to nearly the bottom of the valve, water occupies the space in the hollow disc not taken up by the two port openings, R R, and returns up the stem, D, and watertight connection to the outlet, W. The cylinders of this engine are arranged in pairs, the valves being driven by a vertical shaft passing up between them and geared to the driving wheels of both valves, thus in a four-cylinder engine there are two vertical shafts directly geared from the crank shaft by mitre wheels arranged between the two pairs of cranks. In order to further reduce pressure on the valve face, recesses, H, are provided which are open to cylinder pressure, thereby causing the valve and cover faces to wear more evenly and to maintain a more perfect gas-tight fit.

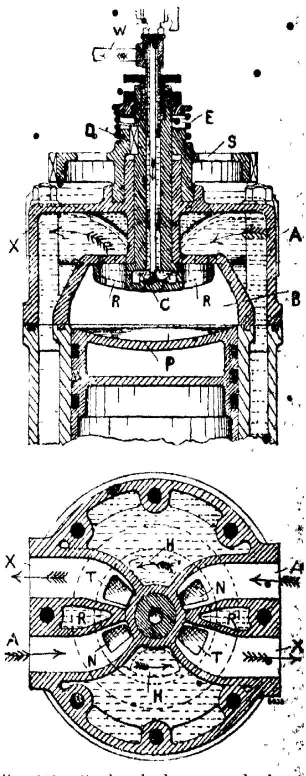


Fig. 131.—Combined admission and exhaust rotary disc valve for vertical four-stroke engine—Raymond

The use of a disc-distributing valve in this manner is by no means new, having been anticipated by Lenoir in one design of compression gas engine made by the Reading Iron Works, a disc valve has also been used by Atkinson and others, who found a tendency for the valve to wear away more rapidly towards the periphery than near the centre. Disc valves have again been tried in high-speed petrol motors, but with indifferent results.

Cylindrical rotary valves have met with more success, the

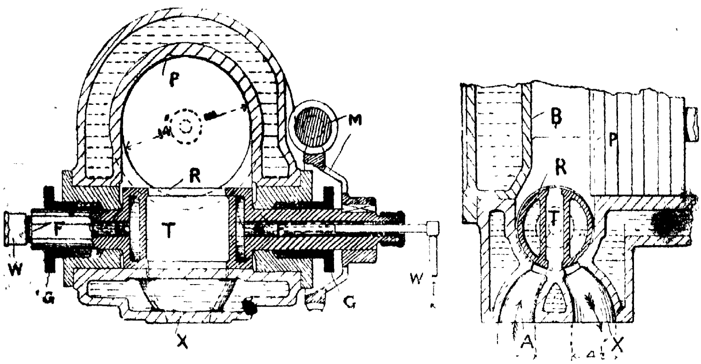


FIG. 132.—Rotary cylindrical valve for admission and exhaust—Wilcox.

usual method of using them being to hold the valve up to its seat by a back-bearing cover, as in the case of reciprocating slide valves. In this form, however, they were never used in engines of more than 10 h.p., and were more often limited to quite small engines—for example, the Crossley and Premier domestic gas engines. The Wilcox cylindrical valve, shown in fig. 132, is arranged right in the combustion chamber, and revolves between two covers, through which are carried two bearing-arm extensions, thus relieving the valve from a too heavy pressure on to its seat. This valve is double ported, and revolves half a turn for each cycle, but as there is only one pair of portways in the valve seat, the area of port opening is consequently not more than one-ninth the piston area, although a very large diameter

of valve is used. The sectional illustrations of this valve are taken from a double-acting horizontal four-stroke gas engine of American construction, in which A and X are the admission and exhaust portways, which are formed fan-shape to communicate with the long port opening, T, in the valve, R; the valve is cast with arms, F F, one of which carries the worm driving wheel, M; the valve is cast hollow for the circulation of cooling water, which enters at W by a pipe at one end and leaves by a corresponding outlet at the other end, each pipe is made a

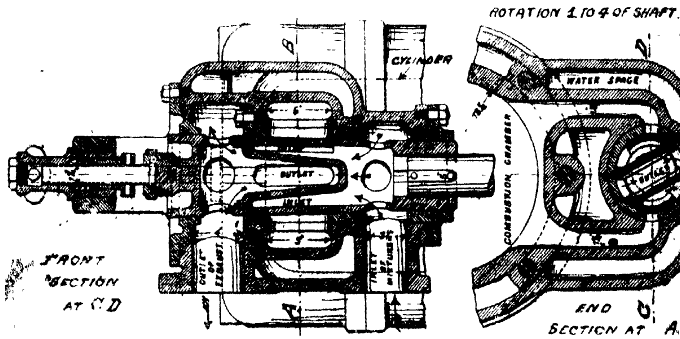


FIG. 133.—Butler combined admission and exhaust rotary valve for horizontal gas or oil engine with 13½-in. diam. cylinder.

water-tight fit by union-nut stuffing-boxes, shown. The two valve arms are also provided with gland-packed gas-tight boxes, G, in their bearings.

This form of valve, if made of "hardened material," and well fitted, should wear for a considerable time without giving trouble, but it seems probable that as the valve wears down on its seat the bearings in the covers will require renewing, unless some provision is made for their adjustment. Its advantage is its extreme simplicity and adaptability for expansion. The valve being water-cooled and free to expand endways, can adapt itself to its seat on the bottom of the combustion chamber provided the side-bearing covers are arranged for automatic adjustment in a vertical direction.

The ordinary rotative plug valve has received much attention at the hands of designers, but, excepting in the balanced self-adjusting form shown in figs. 133 to 136, has not been very widely used. It is true that plug valves have been used just for the admission of explosive mixture and to time the opening to an ignition tube, as in the case of the Clerk and Niel engines, these, however, have been only comparatively small engines, no attempt being made to balance the valves against

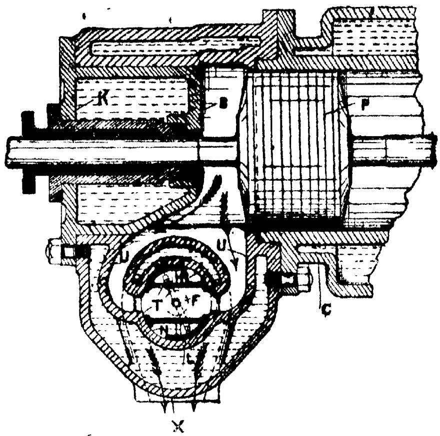


FIG. 134.—Cross-section of Butler combined admission and exhaust balanced-action rotary valve for 20 in. double acting engine.

the pressure of the cylinder explosions. In the Butler balanced form of rotary combined admission and exhaust valve the body of the plug is hollow, or rather cast with three chambers, a central double-ported exhaust chamber communicating with an exhaust outlet at one end and two D-shaped admission-chambers, one on either side, and each provided with a port opening, arranged to communicate with an inlet chamber at the other end. The valve is given approximately an 8 per cent. taper, and is held up to its seat by a small plunger open to the pressure in the cylinder; thus the valve is given practically a floating fit.

In sizes with cylinders larger than 15- to 16 in. diam. the valve is better water cooled at the exhaust end, the admission end being kept cool by the ingoing mixture, which effectually protects the exhaust central chamber walls from contacting with the valve seat. Valves of this construction have been in successful use for more than twenty years, and exhibit but slight signs of wear In ordinary use valves of this kind are found to wear endways about one-fiftieth or so of their mean

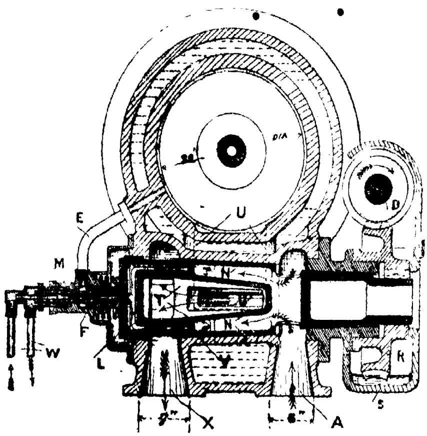


FIG 131A - Longitudinal section of balanced water-cooled rotary valve for double-acting engine.

diameter in a working year, allowance being provided for an end adjustment of one-fourth its diameter. As far as known to the writer, only one of these valves has been quite worn out of its seat, and this in a 15-in. Clarke-Chapman gas engine in daily use for eighteen years, in this instance the running time averaged six hours per day. The valve is more often than not capable of outwearing any other part of the engine, its rotation being only one-fourth the speed of the crank shaft. In practice no attempt is made to lubricate the valve other than at the driving end, the bearing or contact surface, which receives a portion of the carbonised lubricant from the cylinder,

being found after several years' use to be dead smooth and very hard.[1]

In vertical engines (vide figs. 135 and 135A) this valve has been used between two cylinders, the ports in the seat being arranged in opposite pairs to communicate with each cylinder. The valve can thus distribute both for admission and exhaust for two cylinders, and has even been used for three, but in this

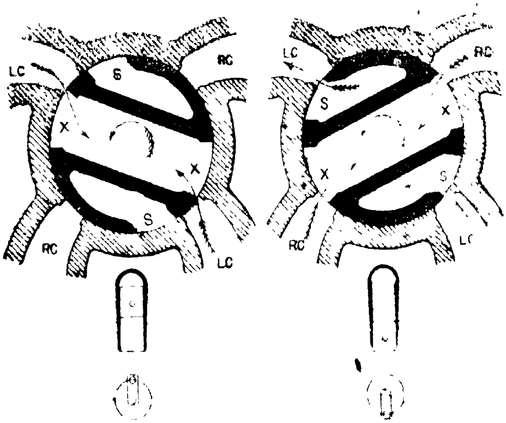


FIG. 135.—Section showing Butler combined admission and exhaust valve arranged for two cylinders.

case the unavoidable length of portway is a drawback. When arranged vertically it is better to use a counterpoise weight to balance the valve against its own weight, a plunger being used, as when arranged horizontally, to oppose the force of the explosion pressure tending to lift the valve out of its seat.

Referring to the sections figs. 134 and 134A, which are taken from a design for a 20-in. double-acting horizontal cylinder, the explosive mixture enters direct from the governor throttle to

[1] A valve in a 13½-in. diam. gas engine after nine years' continuous use (night and day) was found to have worn endways little more than 1 in., and to be file-proof hard on its surface. This engine, which was on full load during the day and on half load at night, frequently made non-stop runs of five to nine weeks.

A, which communicates with the two D passages, N N; the mixture hence enters the combustion chamber, B, by the two oppositely arranged portways and openings, U U, the valve continuing to revolve as the motor piston completes its suction stroke, then cuts off the supply, and further continuing its rotation, will open to the exhaust and release the pressure towards the end of the working stroke, when the exhaust chamber T, will be in communication with both the portways, U U, the complete cycle occupying the time for the valve to turn a half revolution.

In order to retain the valve in a gas-tight working position up to its seat a plunger or piston, F, is placed in communication with the motor cylinder by means of the pipe, E, a continuation of the plunger, M, being carried through a packing-box to the water case at the end of the valve cover, where it is provided with inlet and outlet service pipes, W. Cooling water enters the valve by a tube

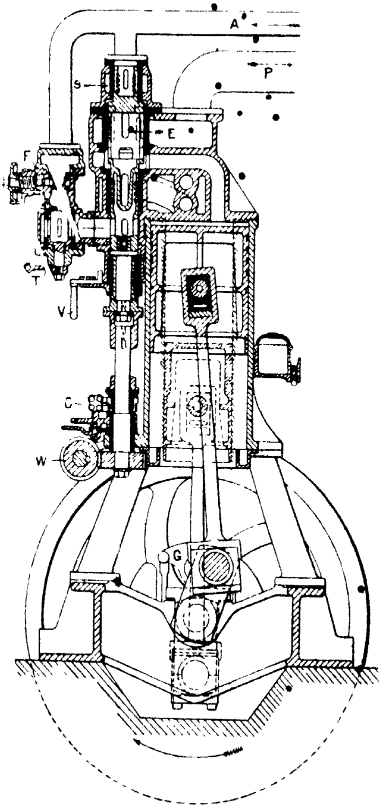


FIG. 135A.—Cross-section of three-cylinder compound Clarke-Chapman gas engine fitted with a rotary balanced action valve.

with a fork extension, L, for ensuring circulation right to the ends of the jacket chambers, and returns along the hollow stem

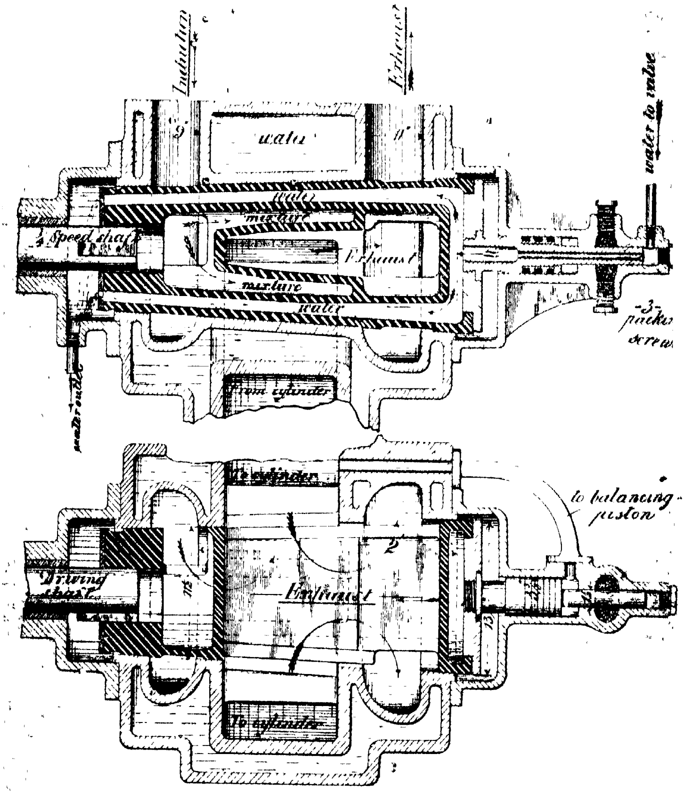


FIG. 136.—Details of water-cooled balanced rotary admission and exhaust valve for a 30-in. double-acting gas engine

to the outlet at W A weak spring is enclosed in the cover at the exhaust end of the valve, and is of just sufficient tension to keep the valve from moving endways out of its seat or from oscillating during the admission and exhaust strokes, when

there is no effective pressure in the cylinder to bear against the balancing plunger. The area of this compensator or balancing plunger is approximately equal to the difference of cross-sectional area of the valve exposed to the port openings U U—*i.e.*, it is equal to the differences in valve diameter at the two ends of the port openings.

At the driving end the worm wheel, R, is journalled on an extension sleeve forming part of the cover, which serves also as a bearing for the valve shaft, which is free to move endways in the driving wheel, R (fig 134A). In some cases liners are provided to facilitate boring and the cutting of the port openings, U U, but as the use of a liner involves a greater thickness of metal between the bearing or contact surface of the valve and the cooling surface, the best results can be obtained when the combustion chamber is bored truly to receive the valve direct. This applies more particularly to the larger sizes, the use of a liner is more convenient for renewals, however, and is the method generally adopted in single-cylinder engines.

As in the working of internal combustion engines, in order to obtain the best results, so much depends on the gas-tightness and timing of the valves, and in multiple-cylinder engines, especially where the number of cams required for operating the various forms of lift valves need the utmost care in their setting to obtain strictly accurate results, any improvement making for an enhanced efficiency of the valves and mechanism used for the distribution of the actuating fluid, whereby the working of such engines can be more perfected, is admittedly one of essential importance, considering the widely extending field of their usefulness.

Engines with Piston-controlled Admission and Exhaust.—Having now described the various forms of admission and exhaust valves used in four-stroke engines, it will be interesting to consider distributing methods more particularly adaptable for two-stroke engines by which the exhaust—and in some cases the mixture also—can be controlled by the motor piston without the use of valves of any sort in the motor cylinder. Engines of this class can be arranged with either an enclosed gas-tight crank chamber or with a separate charging pump which may be arranged alongside. In another construction a long cylinder

with two pistons is used as shown in fig. 138, which represents the Oechelhauser modification of Stirling gas engine now being made in this country by Beardmore & Co. of Glasgow.

All engines which utilise the motor piston to uncover port-

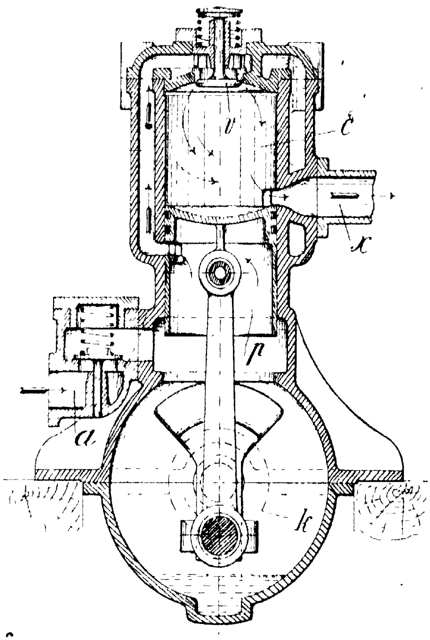


FIG. 137.—Two-stroke engine, with transfer valve on cylinder end.

ways in the working cylinder for the admission of mixture and escape of exhaust gases are constructed to work on the two-stroke cycle, and consequently obtain an explosion impulse at each outstroke of the motor piston.

Referring to the illustration fig. 137, which represents a section of an improved form of petrol launch motor, the piston, p, is made to serve as a slide valve to time the admission of mixture from the crank chamber, k, to the inlet valve, v, fitted

in the head of the cylinder, *c*. By this arrangement there is claimed to be less loss of mixture to the exhaust outlet than obtains in the more generally used form of motor shown by fig. 137A, which illustrates a very simple form and well-known construction of petrol launch motor very extensively made in America, in which country alone there are upwards of twenty separate engineering firms making this type of motor in variously modified forms for marine, stationary, and automobile purposes. These motors are generally built in separate units of from 4 to 6 h.p. each, and are coupled up in twos, threes, or fours. In some cases six separate self-contained motors are connected up to one propeller shaft, the number of motors and not the size being determined by the power required.

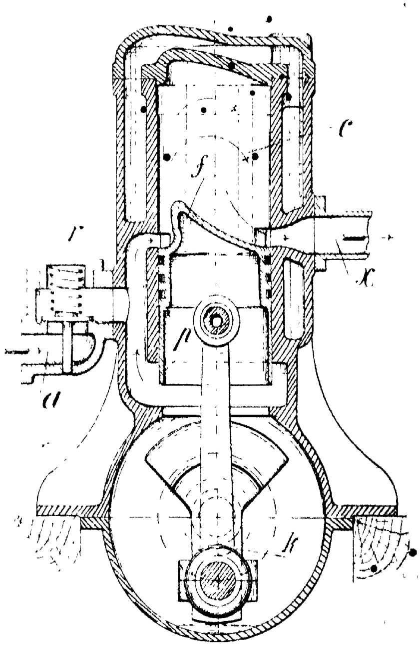


FIG. 137A.—Common type of valveless two-stroke engine with deflecting plate on end of piston.

They are all single-cylinder motors with enclosed crank cases, the mixture of petrol spray and air being drawn first into the crank chamber, where it is slightly compressed on the down stroke of the piston sufficiently to cause it to enter the motor cylinder, and in so doing drive out the spent products of the previous working stroke. The mixture in the example shown in fig. 137, with cylinder-head transfer valve, is driven up the passage in the piston, *p*, and thence by the portway, *r*,

alongside the cylinder to the valve, *v*, where it enters the cylinder, and in so doing drives out the exhaust gases from the last explosion through the outlet ports in the cylinder side at *x*. In the more commonly used form of enclosed crank-chamber motor (fig. 127A) the mixture enters by the passage, *r*, to port openings in the cylinder, and thus drives the exhaust gases out by the port openings at *x* on the opposite side of the cylinder, the exhaust ports being opened in advance of the inlet ports. A deflecting plate, *f*, is cast on the top of the piston for the purpose of preventing the ingoing mixture from escaping with the exhaust gases. Other designs of two-stroke engines adapted

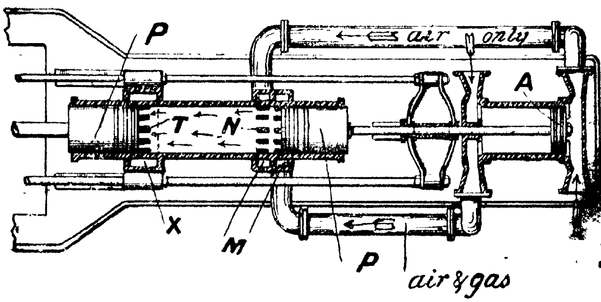


FIG. 138. Two-stroke engine with double-piston mixture and exhaust control — Stirling, Oechelhauser, and Beardmore system.

for running on paraffin, semi-refined and residual oils are shown in Chapter VI.

Motors of this class are claimed to be *valveless*, and they may at any rate claim to require neither a half-speed shaft nor any cam and spring mechanism other than that used for the inlet valve in the crank case. They are well adapted for motor boat propulsion, and are very popular in sizes limited to about 6 h.p. per cylinder for running on petrol, and for paraffin and heavy oils with injection feed up to 40–50 h.p. per cylinder (*vide* figs. 95–102 and 105). For larger powers the form of cylinder design shown by figs. 138 and 142 is more suitable, the mixture here in both cases enters the cylinder at a point as remote as possible from the point of exit. In the double-piston engine a separate piston is used to control the inlet and outlet ports.

N and T, the two pistons, P, being connected to opposite cranks, and so balance one another, this form of engine requires a separate charging pump, and is made in sizes up to 1000 h.p. In the twin-cylinder design (fig. 139) the charge first enters the dual crank case at *a*, and is thence transferred, to the twin cylinders by the communicating passage, *m*, and openings in the cylinder, c^2, the mixture in being driven into the bottom of one

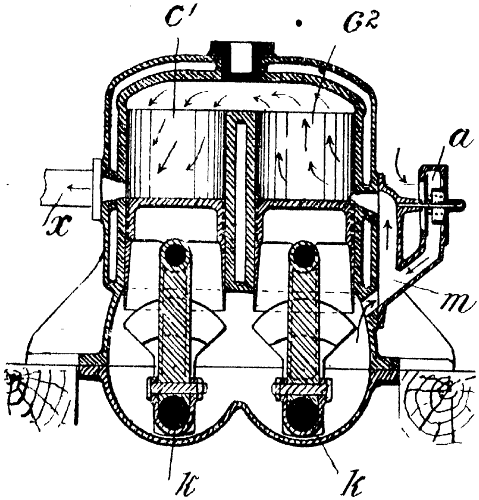


FIG. 139.—Two-stroke engine with twin cylinders and piston-controlled inlet and exhaust—Lucas

cylinder drives before it the products of combustion from th previous explosion out by the openings in the bottom of th other cylinder, c^1, and so into the exhaust escape pipe at *x*. Th two cylinders thus serve for one another, and in a more efficien manner, the purpose of the deflecting plate, *f*, as shown in fig. 137A. This form of motor lessens the loss of explosiv mixture escaping with the exhaust, and enables a wider rang of speed to be attained than with the simple single-cylinde form.

Another modification which is entirely valveless, and adapt

able for larger powers, is shown in fig. 140. Here a double-acting cylinder is provided with a double-ended piston, *p*, thus the necessity for using a gas-tight crank case is dispensed with. Side connecting rods are, however, required as in fig. 138, unless a forked connecting rod is used such as shown at *d*, when one crank shaft is required as against the two separate crank shafts used in fig. 139, which is bad as they require to be connected by gear wheels to run in opposite directions with a balancing action. In addition to the designs shown, there are other forms

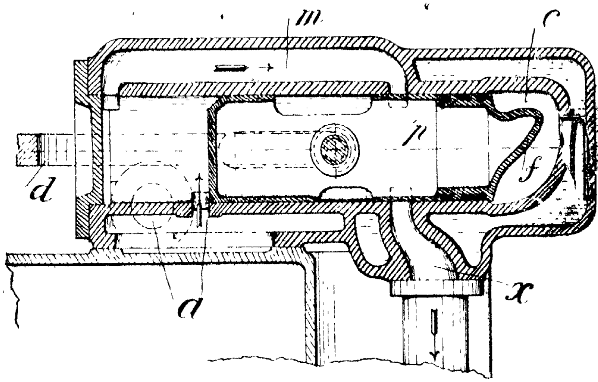


FIG. 140.—Bellamy valveless two-stroke engine.

of engines with a motor piston-controlled exhaust one form having an enclosed front to the cylinder, and another an annular space formed by an enlarged piston running tandem with the power-cylinder piston.[1] Then there must be mentioned the old form of engine with a separate charging cylinder as used by Clerk, and another modification known as the Robson, this having a suction pump acting on the exhaust in place of the mixture supply, two systems that were introduced at about the same time.

In the Gothic oil engine, instead of the mixture for each succeeding charge being forced into the explosion cylinder from a pump, a vacuum is formed by an auxiliary exhaust pump, by

[1] Illustrated in *Internal Combustion Engine Design and Practice.*

which means the used-up or burnt products of combustion are first drawn out and a new charge drawn in during the period that the crank is swinging round an arc of about 25°, the power piston controlling the outlet as in other two-stroke engines. The advantage thus obtained results from being able to draw each charge of vaporised oil and air direct into the working cylinder, thereby avoiding the condensation of oil that would occur by first pumping the charge into a crank chamber or cylinder;

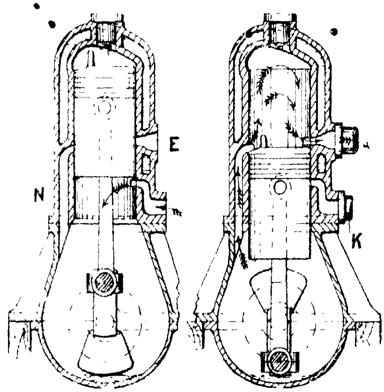


FIG. 141.—Sectional views of an entirely valveless two-stroke engine, showing the piston in positions for charging, exploding, and exhausting, no inlet valve being required to crank chamber.

also, of preventing the petrol or vaporised paraffin mixture from combining with the lubricant.

Perhaps the most interesting two-stroke engine of the kind in which the crank chamber is utilised in conjunction with the bottom end of the motor piston for drawing in and transferring the explosive mixture to the explosion end of the cylinder is the Valveless, illustrated in fig. 141. In this engine, more particularly adapted for motor boats of small size, explosive mixture is transferred from the crank chamber to the explosion end of the cylinder by the portway, N, and consequently does not differ in this respect from the ordinary method shown in fig. 137, the motor exhausting through ports to E in a similar manner. The

peculiarity of the valveless motor, however, is that it is able to dispense with an inlet valve to the crank chamber. For this purpose a third series of port openings, as in fig. 140, is provided communicating with the inlet at K, which may be connected up direct with the carburettor; these inlet ports are kept covered by the piston except at the termination of the upstroke, when, as a partial vacuum will then have been formed in the crank chamber by the exhausting action of the piston, explosive mixture will be drawn in. The complete control of the motor's action is thus affected by the working piston through three series of port openings. There is, however, in this simplified construction the great fault that a less weight of air charge can be drawn in; this method consequently is not adopted for enclosed crank-chamber engines of any but the smallest sizes.

A description of engines with piston-controlled exhaust would be incomplete without a few remarks on large gas engines working on the piston-controlled principle, such as the Korting and Oechelhauser types, previously referred to. For this purpose the diagrammatic illustration fig. 142 will be found to afford a fairly clear idea of the working of the first named. Separate air and gas pumps are used for forcing explosive mixture into the power cylinder through charging valves, N, the pistons in the two pumps being connected to a crank at 190° to the power crank. The charging pumps are provided with piston valves, which are shown in position for gas and air to be forced into the power cylinder, as indicated by the arrows, the power piston just commencing to uncover the exhaust ports, X, leading to E. In practice the charge from the air pump is given sufficient lead to ensure "as far as possible" the exhaust gases being driven out before the admission of the gas charge, the complete operation occupying the period required for the power piston to open and close the belt of ports arranged around the centre of the cylinder. The arrangement of these is set out in the cross-sectional view (fig. 142A) of a 500 h.p. double-acting two-stroke engine with a 25-in. diam. cylinder. Here it will be noted that a wider interval is allowed between the ports at the bottom of the cylinder than the sides and top, this to afford the increased bearing surface for the piston; the exhaust belt, X, is jacketed at T; water is also sprayed into the exhaust to keep down the

temperature. In the double-piston engine, a sketch of which is shown at fig. 138, the action is very similar, the fact of there being two belts of port openings, instead of one, constituting the chief difference, each belt being controlled by a separate single-acting piston; thus additional mechanically controlled admission valves as at N are not required, although some engines of this type are provided with a governor-controlled gas-admission valve.

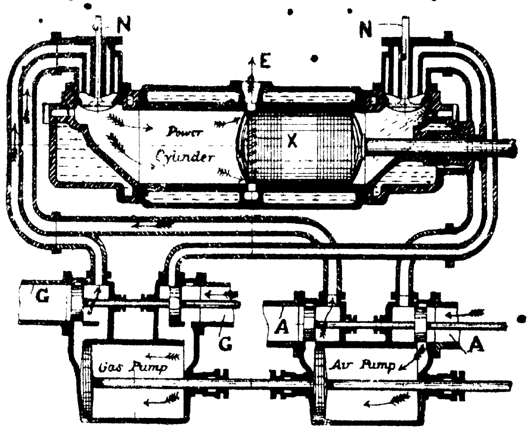


FIG. 142.—Diagrammatic arrangement of double-acting two-stroke gas engine, showing piston-controlled exhaust outlet, admission valves, and charging pumps.

The Junker, Tanner, and Gillespy double-piston oil and gas engines are of similar construction.

On the expiry of the Otto patent in 1900 the two-stroke engine with piston-controlled exhaust fell into disuse on account of its rather greater cost of construction, but for large powers this engine has again been taken up with considerable success. Very large engines in considerable numbers are now being made with single- and double-piston control for use with furnace and producer gas, separate charging pumps being used for the supply of air and gas to the admission ports; this also applies to large-power two-stroke high-compression injection oil engines. In order to further reduce the back pressure of the exhaust gases it is sometimes the practice to use a water-spray injection

in the exhaust pipe immediately under the exhaust jacket round the ports communicating with the cylinder. This is done for the dual purpose of reducing the temperature around the ported belt surrounding the cylinder and diminishing the volume of the gases.

By the use of piston-controlled ports for the admission and exhaust the area for the flow of the gases to and from the

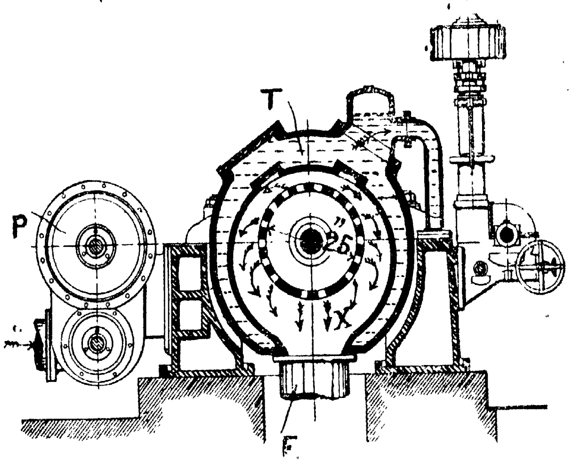


FIG. 142A.—Mid cross sectional view through cylinder of 500-h.p. double-acting gas engine, showing piston-controlled exhaust ports.

cylinder can be increased from the customary proportions used in the four-stroke class of engine,—*e.g.*, from one-tenth to one-seventh (which latter proportion is shown in the table of cylinder and valve diameters given in Chapter VII.) to an area approaching to one-fifth or even to one-fourth of the cylinder area. As the portways are arranged around the full cylinder diameter, the area for a 20-in. diam. cylinder, for instance can be some 70-in., with a width of 2¼-in only, with the ports extending right around the cylinder and with spaces between of equal length to the openings, it will be seen that a total length of 30-in. can easily be obtained (see fig. 142A). It is questionable, however, if any material benefit can be derived from the use of port areas

larger than one-fifth the cylinder area, which give a velocity of inflow or outflow of the gases of less than 83 ft. per second, corresponding to a piston speed of 1000 ft. per minute, and results in a back pressure of very little more than 1 lb. per sq. in., provided short lengths of pipe connections are used with the fewest possible obstructions and, what is important, of a slightly amplified capacity.

Power-piston control can be adapted to four-stroke engines as shown in fig. 162, but involves the necessity for communicating a rotary movement to the piston. Piston valves also can and have been applied in a variety of ways; an example of this is shown in fig. 166 adapted more especially for high-speed engines which remark applies also to cylinder-liner or shell-piston valves, examples of which are shown in figs. 165 and 167. The problem of successfully applying liner, piston, or shell valves for the admission and exhaust distribution of high-speed engines running on the four-stroke cycle is to communicate the required motion without undue complexity, there are other difficulties that increase with size of cylinder, all these have been considered and set out at great length in *Internal Combustion Engine Design and Practice*.

CHAPTER X.

ADMISSION, EXHAUST, AND COMBINED ADMISSION-EXHAUST POPPET VALVES USED IN HIGH-SPEED MOTORS.[1]

IN the high-speed short-stroke automobile type of motor great importance is attached to keeping down valve pocket capacity, as with high compression clearance space in the breech end of the cylinder some arrangements of valves may consist almost entirely of valve chambers and portways. Were it not for considerations of valve-actuating gear, admission and exhaust valves would be more generally arranged in the cylinder head directly over the piston. This method, although entailing the necessity for more complicated actuating mechanism, is now becoming more widely adopted, especially in motors of British and American make. There are various ways of arranging the operating gear,—*e.g.*, a cam shaft may be arranged over the cylinder heads, and be driven through two pairs of gear wheels and a vertical shaft, and in such case is generally arranged to swivel together with its two bearings over to one side in order to gain access to the valves; or the shaft may be fixed up a little to one side instead of centrally, thus giving the motor a one-sided appearance. The valves, again, may be actuated by rocking levers and push rods from a cam shaft arranged low down to one side. By placing the two valves immediately over the cylinder head the combustion chamber can be made of more even form, and side pockets avoided; there is, moreover, a certain diminution in power loss from radiation and conduction, owing to there being less heated surface ex-

[1] Reproduced in part from articles published in *Motor Traction*.

posed to the cooling action of the cylinder jacket circulating water. Valves are, for this reason, placed in the cylinder ends of many large-power oil and gas engines, and in nearly all high-power aero engines.

Another method is to arrange the two valves side by side as shown in fig. 144. In this disposition, known as the L head, the valves V must be at sufficient distance, C, from the centre of the cylinder, L, to allow for a water space between the valves and the cylinder. The distance, T, of the admission and exhaust valves, E and N, will be determined by the diameter of the chambers above and below the valves; in any case the clearance space, P, will be large. The advantages accruing from the "side-by-side" or L head disposition of the two valves are mostly mechanical. For instance, in this arrangement all valve stems and springs may be situated in the front of the motor, and can be operated by one side shaft direct by push rods placed immediately over the cams, all

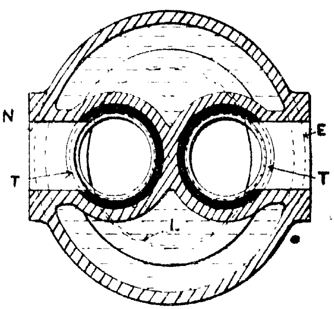


FIG. 143.—Sectional plan of cylinder head in vertical motor, showing arrangement of admission and exhaust valves directly over piston.

levers and extra mechanism are thus avoided; the motor, moreover, presents a more pleasing design, and the valves are more easily accessible. The contra considerations are, as pointed out above, the necessity for more radiating surface in the clearance space, P, and in addition it may be stated that this method is open to the objection of having a more highly heated exhaust valve, owing to this valve not benefiting by the incoming cool mixture as obtains when the admission valve is arranged over the exhaust valve; consequently with this arrangement the exhaust valves and seats are liable to show signs of overheating sooner than if arranged in other ways, to be considered later. Another objection is that the cooling water-jacket does not extend all round the exhaust valve seat, so that

the part next the admission valve is permitted to work at a higher temperature than the other portion of the seat, and naturally unequal expansion results to some extent. There are, however, several makes of automobile motors in which this valve disposition is still used.

The cylinder head, on the other hand, is often arranged as shown by the plan view fig. 145, here the combustion chamber includes two pockets or valve portways, P, the distance, C, of each valve being the same as required in the side-by-side valve

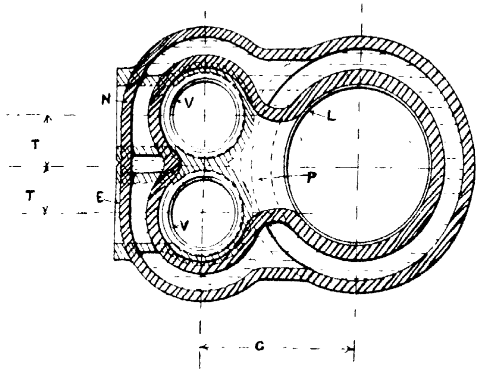


FIG. 144.—Sectional plan of cylinder through combustion chamber, showing the admission and exhaust valves arranged side by side

arrangement shown by fig. 144. The portways and valve chambers in this case have a cubic capacity about one-fifth greater, with a corresponding increased area of surface exposed to the cooling action of the circulating water, consequently the selection between these two forms of cylinder head will be influenced by consideration of the actuating mechanism. The valves when arranged at "opposite sides," or T head fashion, as in fig. 145, require two cam shafts as against one in fig. 144, and although the exhaust valve is more evenly water-jacketed, and therefore less liable to unequal expansion, the latter consideration is a fairly even offset against the use of the double cam shaft, with the result that one finds among the numerous makes

of automobile motors these two forms of combustion chambers used in about equal proportions; the tendency is, however, to adopt methods by which side pockets can be eliminated altogether. The length of the portway, P, can be materially reduced by inclining the valves as shown in fig. 146. the valves in the example given are both on one side, and consequently open to the objection of being unequally water-jacketed as shown by the plan view fig. 144. The valves are, however, brought considerably closer to the cylinder and are not less accessible than in the vertical arrangement, and could of course be arranged "inclined" one at

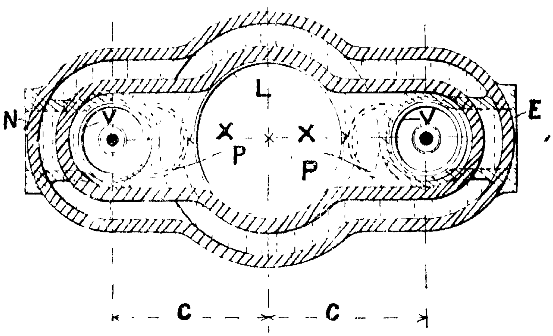


FIG. 145.—Sectional plan through combustion chamber, showing admission and exhaust valves arranged on opposite sides of cylinder

each side, in which case the edge of the valve on either side can be brought "close in" so as to be in line with the cylinder as shown at X in figs. 145 and 146, with a reduction in portway clearance of one-half. The valve stems will stand out as at V, but this can be compensated for by carrying the cam rollers pivoted as shown, thereby permitting the cam shaft to be arranged close in to the cylinder.

The balance of advantages can be obtained by placing the two valves one over the other, both communicating with one pocket as shown in fig. 147. Sometimes, to avoid the additional mechanism involved, the admission valve is not provided with cam-operating gear (see figs. 150 and 151). The more general practice is, however, to adopt a mechanical operating gear,

the admission valve being worked by return levers carried in brackets on the valve bonnet or by a separate push rod. With the overhead arrangement the admission valve and lever has to be removed in order to get at the exhaust valve below; also the general appearance is somewhat more complicated. The admission valve, moreover, is higher up than with valves arranged at the side. These slight disadvantages may be considered as more than compensated for by the cooling action of the ingoing mixture on the crown of the exhaust valve, a consideration of the highest importance in a motor working at high temperature, speed, and power. There is another advantage, as with petrol of ever-lowering grade the exhaust valve assists in the vaporisation of the mixture. For these reasons the combined admission and exhaust valve has some advantage, the ingoing mixture having the effect of keeping down the temperature of the combined admission-exhaust valve exposed to cylinder pressure. This advantage applies equally also to concentric valves, examples of which are shown in figs. 154 to 158. But the greatest advantage of placing the admission valve over the exhaust is in the material reduction of pocket area.

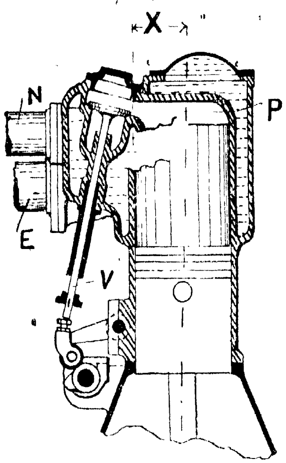


FIG. 146.—Cross-sectional view of cylinder, showing valves inclined in order to reduce the port area

The generally accepted practice in high-speed motors is to arrange for the admission poppets to be opened mechanically, as with the most perfectly attuned springs and valves of the maximum gas-way opening there is considerable drag, and consequent falling off in power output, owing partly to fluid resistance but mostly to back-flow. Automatic admission valves—*i.e.*, those dependent on suction effect for their opening and back-flow for closing—are for the most part fitted with either

compression or extension spiral springs coiled in parallel form; such springs have the disadvantage of opposing a directly increasing ratio of resistance to compression or extension True, some advantage can be gained by using a spring coiled in conical form, or, better still, by using a volute spring coiled from a ribbon of tapering width for the reason that springs of such form oppose a lower ratio of increasing resistance for a given length as the valve is being pulled off its seat In the Silverman, Remington and other methods of suspending the admission valve, with the object of neutralising this tendency as far as possible the valve stem, instead of being connected directly to a spiral or volute spring is connected to a small bell-crank lever in the case of the first named, the long arm of this lever is connected to an extension spring in such manner that as the valve opens there results a decreasing rather than an increasing ratio of resistance opposed to the lift of the valve. In the Remington device two bell-crank levers are used, one pair of arms of these levers is connected directly to the valve stem, and the other two arms are connected together in such manner that the two levers can be held together so as to hold the valve on its seat by one extension spring, the two bell-cranks being fulcrumed on supporting links pivoted to the valve case. The particular effect in the manner of the opening and closing of the

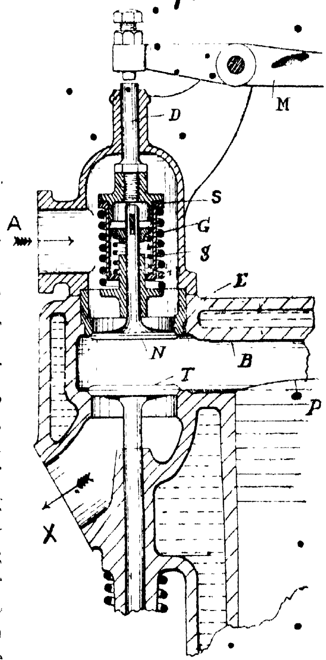


FIG. 147 --Renault combined automatic and cam-operated admission valve.

valve in this way is similar, if not identical, to the Silverman device, the valve in both cases having opposed to it a lower ratio of resistance, which can be proportioned to prevent all chattering or vibrating action during the suction stroke of the motor piston.

In the illustration fig. 148 the action of the Silverman form of non-vibrating admission valve is clearly set out. The valve, V, is held up by one arm of the cranked lever K, the other arm being attached to an extensional spring in such manner that during the opening of the valve, V, it will move through an arc equal to the two chords, C and D, and the versine, B for D, is seen to be about twice that of A corresponding to C, thus demonstrating the decreasing hold on the valve by the retaining spring and the reason why the valve can open to its full extent without vibrating. The fault of this equalising device, however, is the effect of inertia thus preventing its application to high-speed motors.

To obtain a corresponding effect in engines having cylinders of large diameter the admission valves are sometimes provided with dash-pots and other means for steadying their opening movement, the tendency of valves to oscillate when opened by suction effect or atmospheric pressure being caused by the increasing resistance opposed to the opening movement by the spring, and also aggravated, to a certain extent, by adhesion of the valve on its seat. Especially is this the case in oil and producer-gas engines on account of the tarry deposit. For this reason, if for no other, it is preferable to fit a mechanically actuated operating gear, which may be, and often is, utilised to cause the gas- and air-admission valves to close with a variable period according to the load, under the control of a governor, many modifications working on this principle being in use for gas engines of large power. They will not, however, be discussed here, the problem of speed control as applied to the various types of petrol, oil, and gas engines not being a subject to be disposed of in a few lines.

In the Humphries admission valve as designed for two-stroke engines of large power the operation is controlled by a piston which is provided with a set of mechanically-operated pilot valves that are employed for the purpose of governing the

opening and closing movements of the main admission valve, through the agency of air pressure, this arrangement being especially applicable to pressure admission as employed in two-stroke gas engines of large power, in which it is essential for

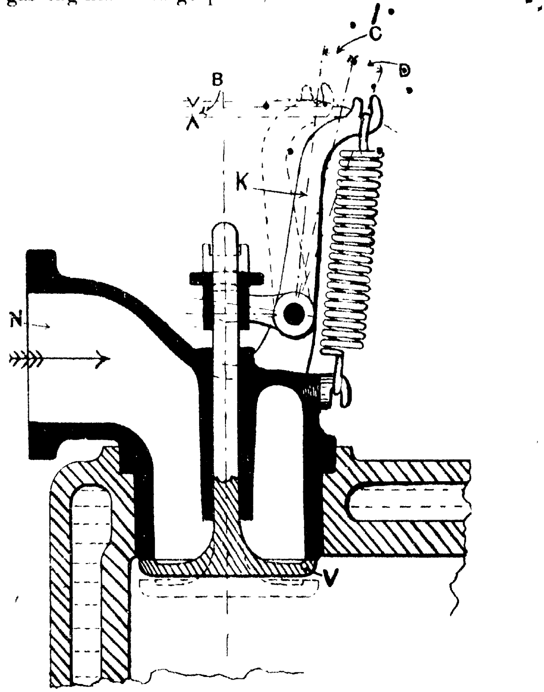


FIG. 148.—Arrangement of "non-vibrating" automatically-operated admission valve—Silverman.

the opening and closing movement of the admission valve to be more rapid than that required for the working of a four-stroke engine.

The springs used to close exhaust valves are necessarily much stiffer than those required for admission valves, as in this case the valve has to be held down on to its seat with a

gas-tight fit by the action of the spring during the whole of the admission stroke, when the suction effect due to throttling or to early closing of the admission valve may attain to any pressure up to 7 lbs or 8 lbs. per sq. in, according to the speed of the engine and degree of throttling action on the supply of explosive mixture. It is for this reason that balanced exhaust valves have a further preponderating advantage in not being subject to a varying suction effect tending to lift them off their seats, and thus result in leakage of exhaust gases to the cylinder during the admission stroke with a corresponding diminution of power.

The four-stroke engine does not lend itself to working without valves as in the case of two-stroke engines, the nearest approach to automatic working in a four-stroke engine can be obtained by a method of pressure-actuated valve mechanism shown in fig 149. Here it will be seen that a four-stroke motor can be made without side-shaft or gear-actuated mechanism of any sort. and, although not valveless, is entirely automatic in its working. The sectional drawing illustrates a vertical single-acting cylinder of the automobile pattern, the cylinder being provided with a port opening as in the two-stroke type of engine, but on a smaller scale, and in this case serves to admit a small proportion of the gases under pressure at the termination of the power stroke, to flow under a piston, H, fitted on the end of the exhaust-valve stem The valve as shown can thus be lifted off its seat, the pressure under the piston being sufficient to open the valve, which is of a smaller diameter, against the spring fitted inside the piston used for closing the valve as soon as the motor piston, P, has arrived at the termination of its exhaust stroke, when it uncovers the port, R, to the crank chamber, and so liberates the penned-up gases under the valve piston, H. In order to prevent excessive lift of the valve its opening piston, H, uncovers a port leading to the bye-pass outlet, L, as soon as the valve is sufficiently raised off its seat, and as soon as the pressure in the motor cylinder has been released the valve settles down so as to close the exit to R, and remains in this position until the motor piston, P, releases the pressure under the valve piston, H, when it immediately closes. The exact timing of the exhaust opening can be determined by the lead of

the port opening at R, the excess area of the piston, H, being sufficient to lift the valve and keep it open during the whole period of the exhaust stroke under all conditions of speed and load. An ordinary admission valve, N, with spring and detachable seat is used, the mixture entering at A in the usual way, and the motor exhausting at X. In order to remove the

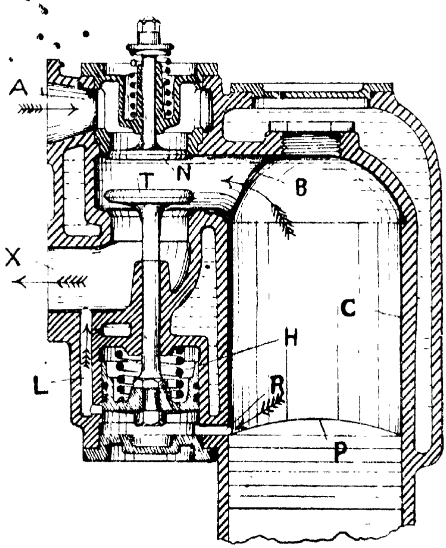


FIG. 149.—Four-stroke motor with automatic admission and exhaust valves.

exhaust valve, the inlet valve seat is taken off and the cover at bottom, when the piston, H, can be easily detached from the valve stem.

Annular-seated and Double-seated Admission Valves.—In the construction and working of high-speed motors great difference of opinion has existed as to the relative values of an automatically operated *versus* a mechanically or cam-opened admission valve. The drawback to the atmospherically opened spring-closed valve is in the restricted lift permitted, this being in practice, very little over one-eighth its diameter and more

often less: in working there is an appreciable hang back or drag in both the moment of opening and closing, the piston having to traverse sufficiently to cause a vacuum of 2 or 3 lbs before the valve opens, while before the valve can close some of the mixture escapes back. It is in the attempt to combine the advantages of both methods that valves of the type shown by fig 147 have been devised In this manner the valve is permitted to open before the timing of the cam, and to close later if the particular speed of the engine should at any time demand it, at the same time, and during the period when the motor piston is travelling at its greatest velocity, the valve is pressed open for more than one-fourth of its diameter, so giving more than double the opening that could be conveniently obtained by automatic means alone.

In this combined automatic and cam-operated valve, A is the mixture pipe, X the exhaust pipe, N the admission valve, T the exhaust valve, B the combustion chamber, P the piston; *g* is a light spring on the valve stem, and G is a stiffer spring which presses against the cam S, at the end of the push rod, D which is operated by the cam lever, M The valve seat, E, forms a guide for the valve stem and a stop for the spring, G, while the weaker spring, *g*, is held up to the collar on the valve stem by a flanged guide screwed into the push-rod cap, S, by this means the two springs are independent of one another in action. Other variations on this principle of combined mechanical and atmospherically opened admission valves, timed to open and close independently of the cam action, so adapting themselves automatically to the varying condition of speed and throttle opening of the motor, have been tried, but are now for the most part abandoned in favour of valves having a definite opening and closing action.

The tendency now is to dispense more and more with any automatic method with its finely adjusted spring, and to rely, altogether on the timing of the opening and closing by a cam, which is formed to keep the valve open during about 200° of the crank circle. This simplifies the adjustment and permits the use of a spring strong enough always to close the valve at the precise moment determined by the cam, at all speeds of the motor.

In several cases the extent of the opening can be regulated by hand to suit the required speed, and as the duration of the opening remains constant, this improved method is accountable in a great measure for the even running of motors so arranged, at quite slow speeds.

In order to obtain an increased opening with the small degree of lift permitted in a suction-opened valve the device shown in fig. 150 has been used. In this annular admission valve an inner seat and portway is provided in both valve and seat. In the Napier valve the centre of the disc is thus partly supported against the pressure caused by the explosions by the bearing around the stem. The openings in the valve provide for an increased gas-way of about 25 per cent., and as this construction permits of an increased diameter, the total opening obtained in this way with the small lift permitted approaches to nearly double that of an ordinary-sized atmospheric admission valve. Referring to the illustrations and other following sections, A denotes the mixture supply inlet, X the exhaust outlet, T the exhaust valve, N the admission valve, B the combustion chamber, and P the motor piston. The admission valve is held up to its seat by the spring S, the lift being limited by the collar on the end of the valve stem to about 3 millimetres, the exhaust valve, as in most engines of this type, is opened by a push rod, D, direct from a cam shaft running alongside the crank chamber, and is usually encased.

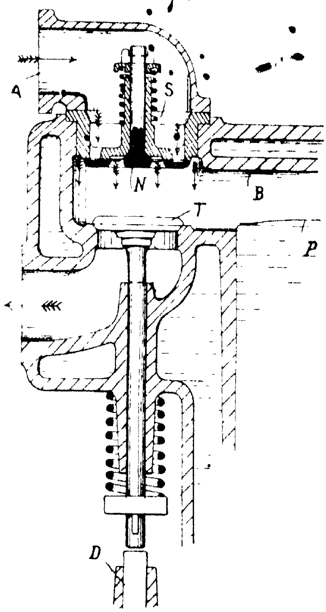


FIG. 150.—Napier annular admission and exhaust valves.

In the Mércèdes device shown in fig 151 there is a multiple seat and triple port opening to the cylinder, and is a modification on the lines followed in the Napier valve In this case, however, a still larger diameter of valve is used, with annular port openings, as in the previous example which rests on a seat with a grid arrangement of port openings forming two circles in place of one. A great measure of success has been obtained by this form of valve in high-power racing motors, the larger diameter permitted giving a much freer opening and requiring a less sensitive spring than would obtain in a smaller valve.

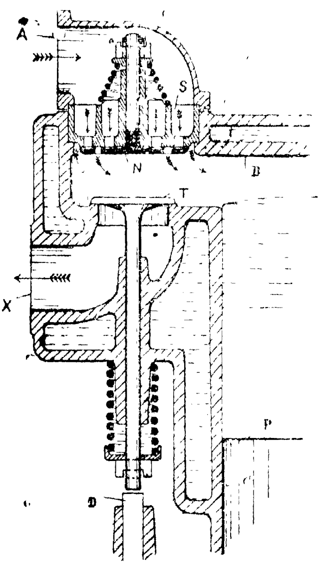


FIG. 151.—Mércèdes multiplex admission and exhaust valves

A third method has been used by the Wolseley Motor Company to obtain increased opening to the ingoing mixture. In large-power motors of this make two, and in some cases three, inlet valves have been arranged in a cluster, their several stems being connected to open and close together Each valve is, however, to some extent independent of its fellows, in being capable of keeping gas-tight on its seat. In using three smaller valves in this manner a larger opening can be obtained than by one ordinary valve, and as the smaller diameters permit of reduced weight and thickness, a quicker action with less drag can be obtained.

To meet the requirements of a very free opening in engines of high power and speed the double-seat valve shown by fig 152 has been designed by the writer. According to this method, applicable also for the exhaust, the valve and seating

is entirely duplicated, and each valve balances the other, so relieving the pressure on the cam as in opening at the end of the working stroke to the exhaust, when the pressure in the cylinder is frequently as high as 40 lbs. per sq. in. This form of valve and seating is capable of giving twice the opening of a single valve of ordinary form, and is made in two separate parts strung on the stem, M, the bottom disc rests on a seat

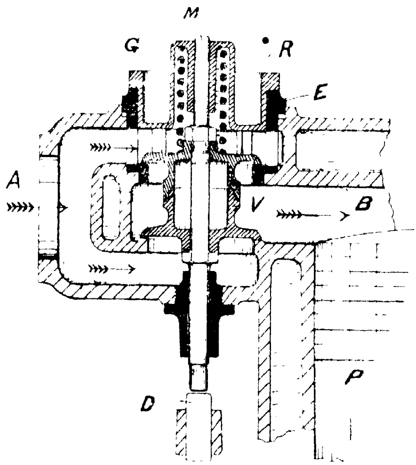


FIG. 152.—Butler double-seat admission valve.

forming part of the cylinder casting, and the upper disc forms a gas-tight fit on the seat E, mixture enters at A, and is admitted above and below the valve along the U-shaped passage, A. The cover, R, which encloses the retaining spring, G, is not exposed to the pressure of the explosions. To remove the valve quickly for examination, the seat, E, is taken out, carrying the valve with it in one piece, the valve can be inspected by removing the cover, R. The advantage of a double-seated balanced action poppet, in addition to reduced friction on the cam mechanism when used for the exhaust, is due to the much greater opening than can be obtained by an ordinary mechanically-opened valve.

In motors used for automobile purposes where very high speeds are used, any diminution of noise, wear, and rattle caused by the valves and operating mechanism is of as much importance as the higher power efficiency obtained, so the slightly increased cost of construction of this form of valve must be discounted to a large extent.

Concentric and Combined Valves.—In explosion engines of the horizontal class, whether using gas, oil, or petrol, it is usual always to determine the extent and duration of the opening of the admission in a similar manner as with the exhaust valve, the additional mechanism required for this purpose being of little consequence when once a side shaft and gearing is provided. In vertical engines, however, mechanically-operated valves in some designs entail the use of a second cam shaft. Such engines may have a well-balanced appearance, but are extravagant in the use of gearing, and require a combustion chamber extending across both sides of the cylinder, as shown in fig. 145, and thus widely depart from the spherical form, giving least cooling surface. Thus it will be seen that designs of combined admission and exhaust valves as illustrated by figs. 153 to 159 permit of a more correctly formed combustion chamber than can be obtained with the admission valves on one side and the exhaust valves on the opposite side or both on one side, whether superposed or L head fashion, and have the further important advantage of preserving a cooler temperature in the exhaust valve, by reason of the ingoing cool mixture impinging direct on to the highly heated valve, thus tending greatly towards longer life and freedom from scaling. The drawback, however, to superposed and over-cylinder valve disposition is the necessity for the operating lever to extend over the top of the cylinder, but it is nevertheless most widely used for vertical oil and gas engines of high power. The most perfectly formed explosion chamber is found in engines having either one combined admission and exhaust valve, as shown by figs. 154, 155, 157, or 158, or with independent inlet and outlet valves, both fitted in the cylinder head.

Efficient cooling of the exhaust valve has indirectly been responsible for more variations and differences in design of valve arrangement than any other cause, and has resulted in the

invention of quite a large number of combined admission and exhaust valves. In thus exposing only one valve in place of two there is less loss from valve leakage; moreover, in all single-valve designs the cool mixture comes into direct contact with the valve and seat, the valve exposed to the explosive mixture under combustion being thus maintained at a lower temperature

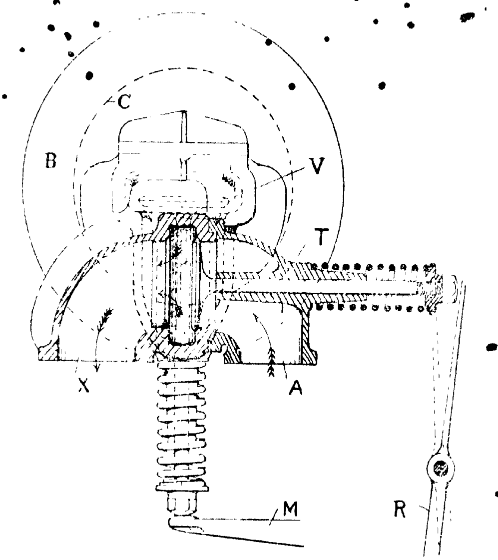


FIG. 153.—Lanchester single valve with double-seated admission and exhaust control.

than is possible in the ordinary way. By this arrangement it has been possible to run successfully air-cooled motors of considerable power,—*e.g.*, the Lanchester automobile motor, in which a single-pressure valve, as illustrated by fig. 153, has been successfully used. This is really a combination of two valves, one exposed to the cylinder, V, and one double-seated valve, T, which is caused to close either against the admission inlet, A, or outlet, X, the pressure valve, V, remaining open during both admission and exhaust strokes of the motor piston. In this manner the

cool petrol mixture entering at A when the valve, T, is closed to X by the tappet lever, R, flows up past the exhaust and explosion-heated valve V and seat when opened by the lever, M.

Another form of combined inlet and outlet valve is shown in figs 154, 154A, and 154B Of these the Selbach valve is rather an interesting design, and consists of a pressure poppet, V, which seats gas-tight in the cylinder head. There is in this combination a controlling sleeve, N, which is open to the mixture supply at A at one end and when the poppet V, is sufficiently depressed by the lever M, the sleeve, N, is pressed down to the seat, T thus closing the exhaust outlet to X and by a further depression the poppet, V, is pushed off the seat at the lower end of the controlling sleeve, N, thus putting the cylinder into communication with the supply pipe at A. In working, of course, the poppet is first depressed to the position for the exhaust stroke of the motor piston, and is then further depressed so as to open communication for the next charge of cool mixture following on the induction stroke of the piston, as shown in fig. 154A The poppet, V, first contacts with the end of the sleeve, N, on its return, and, continuing, carries the sleeve up until it closes against its seat in the cylinder head. It will be seen that the poppet thus has a high lift, and, although maintained comparatively cool by the ingoing mixture, the hammering action, due to the excessive lift, results in a clattering effect, which nullifies any advantage due to the use of a single cam and lever and improved form of combustion chamber.

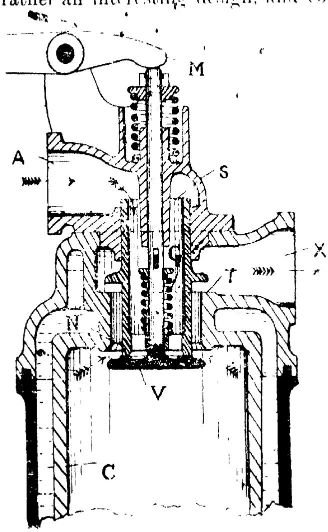
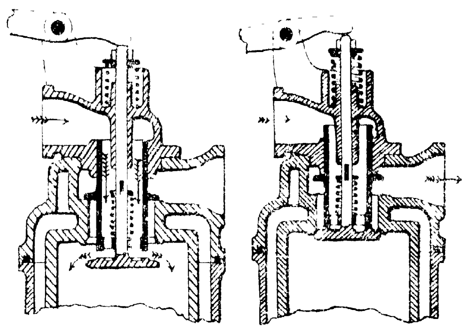


FIG. 154 – Selbach combined admission and exhaust valve, shown in position for exhausting.

In the Selbach valve there are three seats altogether, as well as a sliding fit of the upper end of the sleeve, S, which separates the exhaust passage from the mixture intake at A. There are also two springs one, G used to hold the poppet, V, up to the end of the sleeve S, unless depressed by the cam lever, M, consequently from a point of view of economy in construction it has more parts than the ordinary arrangement of separate admission and exhaust poppets. In its favour however, may be mentioned neatness of design, with only one seat exposed to the heat and pressure of the explosions. In



FIGS. 154A and 154B.—Sectional views of Selbach valve shown in wide-open position for admission, and closed as for the compression and combustion strokes

addition it may be further stated that there is a cooling action given to the poppet, V, by the ingoing cool mixture down the sliding sleeve, S, which should tend to counteract to some extent the ill-effects of the high lift necessary.

Another form of valve designed for high-speed automobile motors is shown in fig. 155. In this example there are two poppets, one of which is hollow and contains a second poppet, the outer being generally used for the exhaust and the inner for the admission of the mixture. In the Parsons petrol-paraffin launch motor this order is reversed, the outer poppet being used for the admission of mixture, and is utilised in some cases together with its chamber as a vaporiser, the spray and air being circulated around the heated wall of the hollow poppet,

which is maintained at a high temperature by the passage of the hot exhaust gases down its centre, and has been found capable of permitting the use of paraffin oil in motors so fitted after they have been first thoroughly warmed up by petrol. Indeed, in a form closely resembling the illustration, a horizontal engine was built some years ago in which a combined admission-exhaust and vaporiser valve was used, this arrangement having been devised by James Virtue, primarily with the view of being able to use flash-proof oils satisfactorily, the oil spray feed was pumped into the hollow stem of the exhaust poppet, which was made very long in order to thoroughly vaporise the mixture. In this instance the inner admission poppet was held down by a tension spring and opened by suction In the Equeville ring or concentric combined admission and exhaust valve this method was also used, the combination of a pair of poppets, the outer serving as the seat for the inner, being devised more for the purpose of preventing the exhaust poppet from getting overheated, than for any other reason.

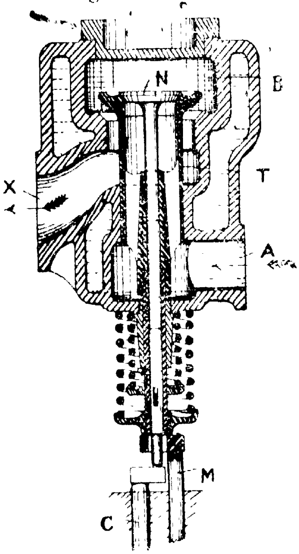


FIG. 155.—Combined admission and exhaust hollow valve—Equeville, Parsons, and others.

In the Loutsey design both poppets, as shown in fig. 156, are mechanically opened, the outer ring fitted in the cylinder head being of maximum diameter Although at the first glance it might appear that this arrangement exposes only one seat to the cylinder pressure, in reality there are two seats under pressure, and with the exception of the advantage due to cooling action of the ingoing mixture, there can be but little in its favour except in the use of an improved form of com-

bustion chamber, and in affording a much greater gas-way opening, which is important for high speeds. However, as in practice this combination permits of the possibility of using heavier grades of petrol and even paraffin, it must not be compared simply from the point of view of an admission and exhaust valve.

These two designs are really very similar, the latter differing principally in having three stems as against two and in being placed directly over the cylinder as against the side. The worst feature of the inverted design (fig. 156) is the elongated cylinder head, which must be taken off for access to either valve; it, however affords more than double the gas-way than is possible with a pair of admission exhaust valves, or even with four valves, and without increasing the lift. Referring to the illustration mixture enters at A and down the hollow ring poppet, X, which is first depressed by levers pressing on the twin rods, D, during the exhaust stroke; immediately following the closing of the outer valve the central poppet, V, is depressed by the stem, B, for the admission of the charge. There is thus nothing abnormal in the operating of the two valves, each working independently of the other. The fault in this well-thought-out design is the great weight of the outer poppet, as this in common with the concentric design shown in fig. 155 clearly has not only to carry a hollow piston or sleeve extension, but the admission poppet as well. The Parsons design is lighter, and also lends itself in an inverted position as a cylinder-head combined admission and exhaust valve. Referring to the illustration (fig. 155), A is the intake for explosive mixture, N the admission poppet, B the combustion chamber, T the

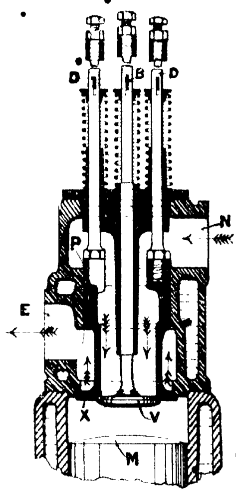


FIG. 156.—Arrangement of concentric combination valve in cylinder head for admission and exhaust— Loutsef.

hollow exhaust poppet and C and M the two push rods used for mechanically raising both poppets from their seats independently of suction; the rod M, as shown, raises both together for the exhaust, and on the admission stroke the hollow poppet is closed by the larger of the two springs, the inner poppet being held up by the rod C. Neither poppet is required to have more than the ordinary lift, and except for the necessity of requiring a free sliding fit to the sleeve extension in the bearing between the intake chamber and exhaust outlet, which consequently must be gas tight, there appears to be no reason to prevent this form of combined admission and exhaust valve from working satisfactorily.

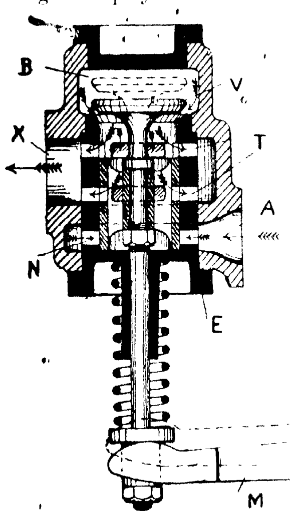


FIG. 157.—Combined admission and exhaust valve with controlling sleeve on stem—Weatherhog and others

The Weatherhog design, fig. 157, is an early form of combined admission and exhaust valve with a sliding sleeve and single control, which has been used extensively in small industrial gas engines. This consists principally of a poppet valve of ordinary construction provided with a ported sleeve keyed to its stem, which serves to put the poppet into communication first with the exhaust outlet at the first stage of lift, when the valve is raised still higher off its seat, and in this way carries the sleeve with it, thus closing the ports leading to the exhaust and opening communication thereby with the mixture supply. In the illustration the piston is shown open to the exhaust, X, by the ports, T, which permit a free passage for the exhaust gases past the poppet, V, and openings, T, to the exhaust outlet, X. At the termination of the exhaust stroke both poppet and sleeve are given a further lift to the position

shown in dotted lines, when the openings, T, will be closed and the bottom edge of the sleeve raised so as to open up the ports N, to the poppet, V. The mixture supply then is free to flow up through the sleeve to the combustion chamber, B. With a combination valve of this design provided the sleeve is a gas-tight fit in its cylindrical seat, E, an engine of small size can be worked satisfactorily. The tendency is, however, for the seat, E, and sleeve to get too hot for a sliding fit, it being impossible to efficiently water-jacket the working parts, and as a result the fit soon wears slack and allows such leakage between the intake and exhaust as to considerably reduce the power of the engine and to cause such back-firing under certain conditions as to prevent further working until the engine is refitted with a new sleeve to the ported liner, E. The poppet also requires a very high lift and works somewhat in the manner of the valve previously described and illustrated by fig 154, but in this case there is only one seat to the poppet, and the fit of the sliding cylindrical ported sleeve, E, is relied on to intercept leakage of hot gases from the openings, T to the flow of gas mixture on the charging stroke of the engine. For very small cylinders with a separate cut-out on the gas supply this form of valve has been found to work fairly well on reduced loads when cooling charges of air can be taken in at intervals between the explosions.

Obviously a concentric valve is not a single-seat valve, but rather a double valve, both seats being exposed to cylinder pressure, and each poppet arranged for independent control. The outer poppet is provided with a sleeve fitted with rings so as to form a gas-tight fit between the induction chamber and the exhaust. All the moving parts of the exhaust poppet can be surrounded by a water-jacketed space, and this valve, in addition to being of an exceptional diameter, is further cooled by admission of the cool mixture down its centre, and thus presents a practical method for preventing overheating in an engine of high power where water-cooling of the exhaust valve would be inexpedient. In connection with valves of this type it is obvious that the functions of the inner and outer poppets may be reversed, the central poppet being used for the exhaust, and the annular outer poppet of larger area for the admission of the charge.

By adopting the reversed functioning of the inner and outer poppets much less cam force is required to open the exhaust poppet against the terminal pressure of the cylinder gases. On the other hand, the exhaust poppet being within the admission poppet, would not be water-cooled, although its seat would have the advantage of the cooling effect of the ingoing mixture all around it. There is also another aspect to this question of which poppet to use for the exhaust: if the outer opens first for the exhaust stroke, it carries the admission with it; this poppet, therefore, on the induction stroke of the motor will simply have to be retained in its open position while the outer poppet closes. If, *per contra*, the inner poppet is opened first, it will have to be closed against its seat in the outer poppet before this is opened for the induction stroke, or the result will be that for a time both will be open together. There would also be the possibility of the two poppets moving in opposite directions, and clashing with unnecessary force. A concentric ring or annular valve, with the outer poppet controlling the exhaust, will be found to have the advantage not only of resting on a water-cooled seat, but of having quite half the surface exposed to the heat of combustion occupied by the inner admission poppet, which, owing to the cooling action of the mixture supply, never gives trouble from overheating.

With valves arranged for the combined functions of admission and exhaust there is yet another point for consideration, which is—in common with all motors having the inlet placed over the exhaust—the tendency to attenuate the ingoing mixture, and in consequence to reduce the weight of the explosive charge which can be drawn into the cylinder during the induction stroke, a cause that results in much loss of power in many motors when at all overheated. In large stationary gas engines of the vertical and horizontal types, where the practice is almost invariably to place the inlet over the exhaust, this tendency can be minimised by water-cooling of the exhaust valve, consequently the advantages which are found to result from this disposition cannot be compared on quite parallel lines with a motor in which the ingoing mixture is caused to impinge on an exhaust valve which is not water-cooled; this consideration, therefore, is an argument in favour of a motor with separate valve pockets and cam shafts,

or for locating the valves in the cylinder head, unless some feasible method can be applied for preventing the exhaust valve from acquiring a high temperature.

A very light construction of concentric combination valve with exhaust control on the outside is shown in fig. 158, arranged over the cylinder head of an air-cooled aero motor, consisting of

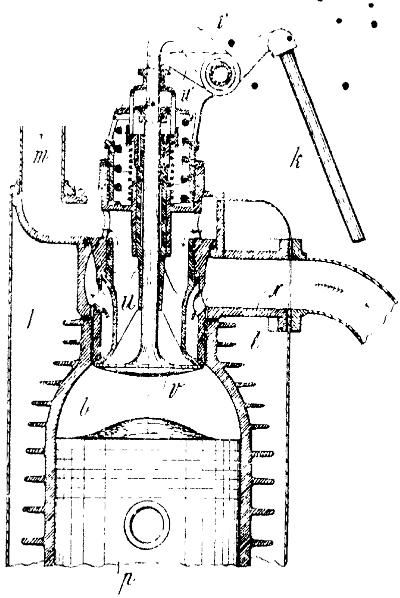


FIG. 158.—Combined admission and exhaust valve for air-cooled aero motor.

four cylinders arranged diagonal fashion to drive on to a double-throw crank shaft, this being a construction that has the advantage over the single line vertical form of motor on account of its reduced length. Referring to the figure, it will be seen that a poppet valve, v, is guided within and seated on the end of a sleeve poppet, u, which seats on to the fixed casing, l. As in the preceding examples, both poppets are opened together by the simultaneous action of two cam-actuated rods, k, and levers, v'

at u', for the exhaust, which, as shown by the arrows, escapes by the pipe, x. At the end of the exhaust stroke of the piston, p, the exhaust sleeve poppet, u, is closed the poppet v, being held open until the termination of the succeeding induction stroke for the admission of explosive mixture from the inlet, m. This type of valve, as explained, is more correctly characterised as a double valve than a combined valve, there being two seats, it, however, has the advantage of affording a greater gas-way area than can be obtained by two or even three separate poppets when arranged in the cylinder head side by side. In this motor the cylinders are cooled by air circulated by a fan through the jacket space, j, the four cylinders being so disposed that all the valves can be conveniently operated from one cam shaft. Another point in this design is the large gas-way area afforded by the inner poppet this being nearly equal to that of the outer, which is important in motors required to run at a very high speed.

CHAPTER

REVOLVING AND RECIPROCATING SLEEVE, LINER, PLUG AND PISTON VALVES FOR HIGH-SPEED MOTORS [1]

It will have been noted in the foregoing chapters that the majority of the valves devised for the improved working of internal combustion engines may be classified as lift or poppet valves in various forms and combinations and that one feature in their working is particularly distinguishable viz., their entire dependence on spring action for closing. It may therefore be stated here that this drawback, more than any other incident in their working, has been the responsible cause of many of the improvements in valve distribution, having for their aim the development of some form of valve having an entirely positive action.

Revolving Plug Valves.—The first attempt in this direction was made by the writer, who fitted a two-cylinder double-acting petrol motor for a small tri-car made in 1887–88 with rotary balanced-action admission-exhaust valves, and later fitted a valve of similar construction to the motor of a small car made in 1898. This valve, shown in fig. 159, will be seen to closely follow other rotary valves designed by the writer for gas and oil engines, described in Chapter IX, but it is interesting in being the only really successful rotary valve applied to a road-car motor. This valve is still in existence, and shows little signs of wear after being in use for nearly seven years, during which period the car required to be fitted with an entirely new set of speed-gear wheels and two sets of tyres. The illustrations are

[1] Reproduced in part from articles published in *Motor Traction*

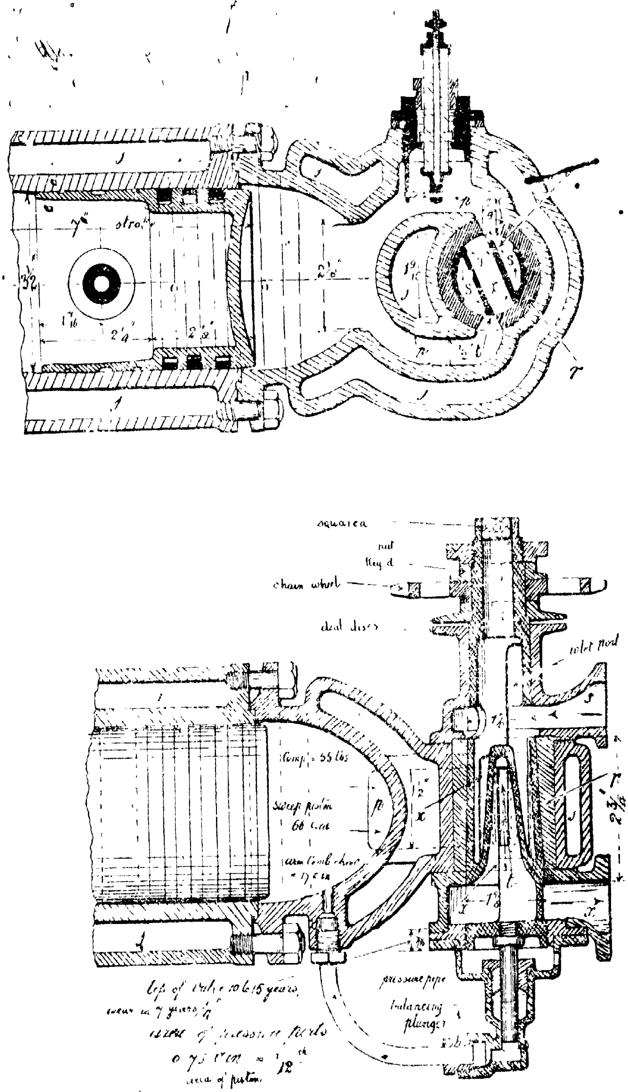


FIG. 159.- Cross-sectional elevation and plan views of rotary admission-exhaust valve used on Butler single-cylinder motor-car (1898-1905).

self-explanatory and dimensioned. The valve, or rather the liner, *v*, is water-cooled. both valve and liner are of hard cast-iron, and, after once ground to fit, require no further attention, as endways wear equalling about one-sixteenth of an inch for a year of 200 hours' running time maintains the pressure surface bright and smooth. Wear and expansion are automatically compensated for, the valve being held up to its seat by a plunger open at the larger end to the combustion chamber. The valve was driven by a chain-and-sprocket wheel from the half-speed shaft previously used to operate an exhaust poppet valve. The valve, which revolves one turn for four revolutions of the engine shaft has a taper of 1 in 11, and duplicate inlet and outlet ports, *s* and *e*, which register with a pair of slots, *t*, cut in the liner at each half-turn. The driving end is supported by a parallel extension and provided with an index disc for setting the valve to a mark on the fixed disc, when a mark on the flywheel is turned round to its pointer. thus the valve can be accurately set with the minimum of trouble, in fact the valve can be taken out and replaced well within four minutes, not that this is much of an advantage, as very little carbonised oil is found to collect on the port edges The liner is thick, and thus capable of maintaining its true curvature against unequal pressure of the bore in the combustion chamber. this is important.

The valve, as explained in Chapter IX., can be applied to control both the admission and exhaust of two cylinders, as shown in figs. 135 and 159A For this purpose there should be two pairs of portways, as G H, cast to coincide either with two pairs of slots cut in a liner, as at R, or to open into the valve seat and be trimmed so as to be accurately spaced and of equal width. As shown, the valve is driven by a central shaft from a worm-wheel gearing on to a worm of large diameter, and keyed on a disc turned on the engine shaft midway between the two cranks: this makes a very neat and direct drive, and can be applied to a vertical engine.

In applying this form of rotary valve to control the distribution of admission and exhaust for two cylinders it is really better to dispense with the liner, as there is a tendency for the gases under pressure in one pair of ports to leak across

behind the liner to the other pair of ports not under pressure, even when the liner has been made a taper fit and ground in; the reason for this is the distortion that takes place in the ported cylinder heads, and is not to be wondered at. However, it is not difficult to slot the ends of the portways so that these shall be equidistant. On arranging the valve for a vertical engine, it is better to have it horizontal between the two pairs of portways than in a vertical position at the side, this, then, adds to the necessary gearing for the drive. Obviously, the valve must be

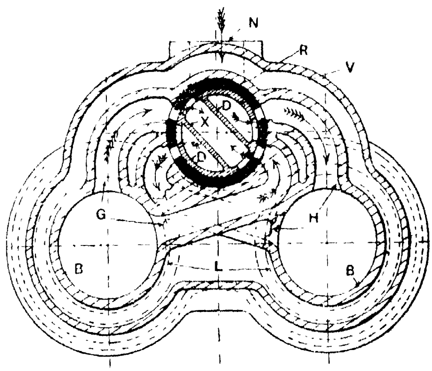


FIG. 159A.—Cross-section showing balanced-action rotary admission-exhaust valve applied to a double cylinder horizontal, 5 in. 6 in., car motor.

absolutely free to move endways, thus the driving wheel must be mounted on a sleeve extension of the valve-stem cover. It must not be understood that the valve will not work satisfactorily in a vertical position, but simply that it is better balanced and more accessible in a horizontal position; this position also lends itself for a better disposition of the two pairs of portways.

The fault of the valve is the care required in fitting; also, being entirely different from accepted practice, there is considerable prejudice evinced both by users and repairers. Then, again, the cylinder head is somewhat intricate, and must be cast in one piece; the valve seat must be accurately bored to the exact taper, and does not lend itself to the simple method applied to poppet

seats, finally, both valve and seat must be hard cast-iron and well ground in. Thus, although taking the place of four poppets, as well as affording large and accurately timed port openings and smooth running, and this quite independent of speed, this unique form of valve has made but little headway with high-speed motors. The most notable adaptation is the Itala rotary valve, for which much has been claimed; this, arranged to control the admission and exhaust to a pair of cylinders, is very similar in form to the valve described, being balanced and double ported; it, however, differs in detail, and is in part water-cooled. Besides this, there have been a number of rotary valves of one kind and another, mostly with parallel sides or cylindrical, unbalanced and single ported, but none of these have survived a season's wear.

Revolving Cylinder and Piston Valves.—One essential for success in a rotary valve is that it shall be tapered, and free to adapt itself for wear and varying expansion; thus it will be seen that no form of parallel rotary valve can be a success; it is impossible to make such a valve gas-tight, for the all-sufficient reason that surface packing keys are impracticable; they cannot be held up against cylinder pressure. The only other rotary valve that has been made to work is Crowden's combined revolving cylinder and valve shown in fig. 160. In this motor, designed for a launch, the valve constitutes a tapered extension of the cylinder, *c*; this consequently revolves with it. The cylinder is rotated one turn to four revolutions of the engine shaft by a worm-wheel gear *m r*, the cylinder, *c*, valve, *v*, and driving wheel, *m*, are held up by a ball-bearing race, *g*. The reaction pressure against the cylinder head is taken up by the adjustable ball-race, *h*. There are thus seen to be one or two problems in this design that require some careful thinking out. However, credit is due to the inventor in having mastered both the pressure and the expansion difficulty, the solution of which has been materially assisted by a copious circulation of water up through the jacket from *w* to *w*, and lubrication of both ends of the cylinder at *l l*. In practice it has been found that owing to the valve and seat being so completely water-cooled there is really very little differential expansion, so that having once ground-in the valve to its seat and adjusted the height of the

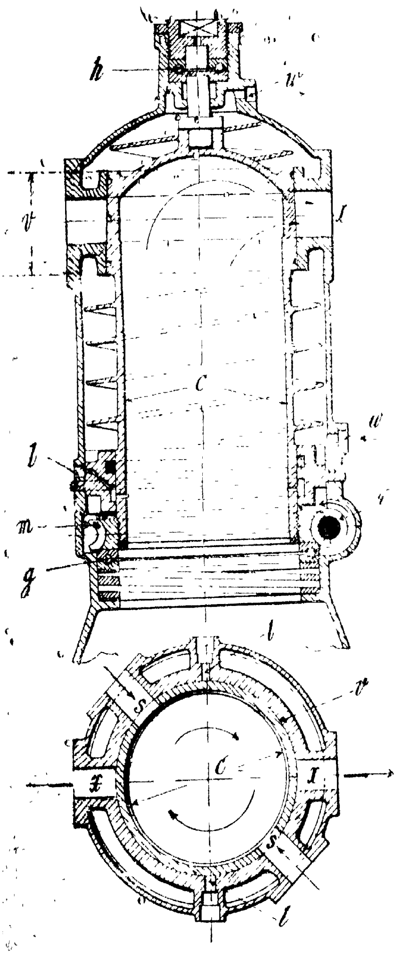


FIG. 160.—Cross-sectional elevation and plan views of cylinder of Crowden petrol motor with revolving cylinder valve

cylinder by the thrust bearing, *h*, to allow a free running fit, the engine can be started up. Any leakage can be at once seen by bubbles escaping with the circulating water, and in an experimental motor of small size that has been run under varying conditions leakage of water into the cylinder is entirely prevented by the oil film on the valve seat. The principal objection to utilising the cylinder in this manner is the head bearing, which has to resist the full pressure on the piston, less inertia and weight of cylinder, there is also the ignition, but this problem has been solved by arranging for the igniter to fire the charge through the ports, *s*, and is for this purpose fitted in the outer casing to coincide with the cylinder ports at the end of the compression stroke.

Although not obviously so at first

sight, distribution of the admission and exhaust has been designed to be effected by a combined valve and revolving cylinder, shown in fig. 161, but in this design the inventor has gone a long way round to cut out a transmission gear, quite regardless of the extra cost and mechanical difficulties involved. It is, however, an indication of enterprise and an example of ingenuity and of what can be done, and is therefore not without some interest. Referring to the illustrations, it will be seen that the piston, p, is annular, and surrounds the water-jacketed revolving cylinder, e. Rotary motion is communicated to the cylinder by the sliding action of the piston by means of grooves, g, on the outer wall of the cylinder and roller, r, on the outer wall, v, of the piston. The cylinder head is carried by a ball-race, b, on the top of the outer casing, c; in this there are also grooves, e, to prevent the piston twisting on the crank rod. Distribution is effected in the usual manner by a port, t, in the cylinder head, which registers during rotation, with openings, s x, in the outer casing. The most interesting feature of this design is the spring, n, for ensuring

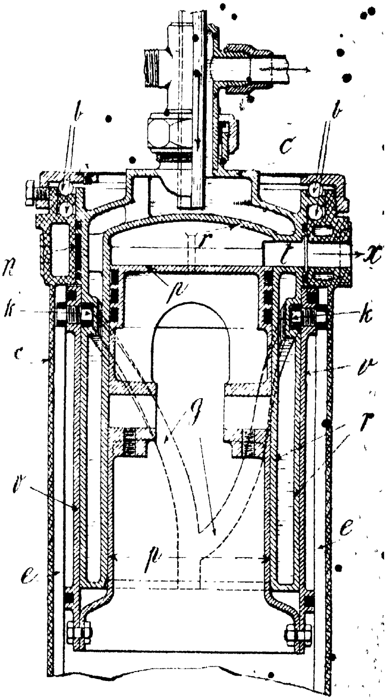


FIG. 161.—Sectional elevation of Parker's motor, showing combined cylinder and valve rotated by cams engaging with an outer sleeve on the piston.

a gas tight fit between the cylinder and casing, which is the fault of all revolving cylinder liner and sleeve valve distributions, due to unequal expansion wear and to the difficulty of fitting adequate packing to prevent leakage of pressure gas during the compression and working strokes. Before proceeding to describe some methods that have been devised to correct this fault, it will be appropriate to bring to notice the Dawson revolving piston distribution, which may be accepted as the prelude to all subsequent adaptations of the revolving principle, from this it will be seen that the difficulties of obtaining a really practical distribution by causing the motor piston to revolve are quite as great as with a revolving cylinder. In the example shown in fig. 162, for instance, the piston was provided with a cylindrical extension, P, of a length exceeding the stroke plus width of port, the piston, which was rotated at half the speed of the crank shaft, M, by the rod, D, and gearing, G, was fitted with a V shaped double portway, V, which registers with the outlet T, during the upstroke, and with the inlet, N, during the following downstroke. A fixed piston cover, K, serves to reduce the space over the working piston to the limit required for the desired degree of compression. The drawback, however, to the revolving piston is the difficulty of arranging a durable mechanism connecting the piston rod

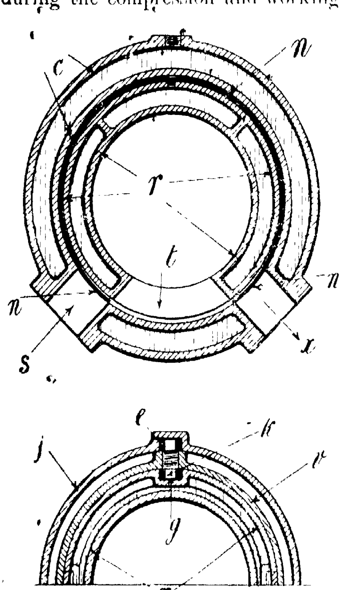


FIG. 161A.—Sectional plans of Parker's revolving cylinder valve.

with the crank, to which may be added the ball-and-socket attachment to the piston, the expense of this construction far exceeding the advantages gained.

Obviously there are great difficulties opposed to the successful working of a combined rotating and reciprocating piston, especially when required to run at high speeds, while the enormous friction set up by the rotative action, and the difficulty of keeping the piston gas-tight, make it very improbable that this method will come into any considerable use.

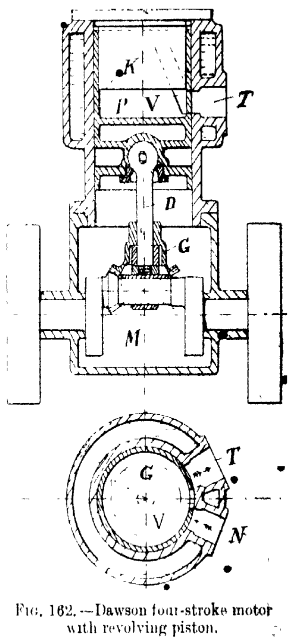


FIG. 162.—Dawson four-stroke motor with revolving piston.

Revolving Liner Valves.—A method on parallel lines to the sleeve-extended revolving piston has been suggested which commends itself at first sight by its simplicity of construction—viz., the use of a revolving liner between the cylinder proper and the piston, such liner to be geared at its lower end to rotate one turn for each cycle of two revolutions, and be provided with a port which very conveniently can be caused to register with an induction and exhaust port opening during its revolution. Now, with a liner there is not the difficulty experienced in the case of a revolving cylinder or piston; there is, however, the same objection of excessive friction set up by the high speed of rotation and the difficulty of running for long a gas-tight fit. Partly to avoid this objection, it has been proposed to rotate the liner between a fixed inner liner and the cylinder proper, such an arrangement, if properly constructed, being capable of relieving the revolving liner from the thrust of the piston. It

is open to grave objection, however, on the score of unequal expansion, difficulty of efficient lubrication, and increased working temperature of the motor piston, and last, but not least, the extra cost. The various aspects as presented by a motor constructed on these lines cannot be definitely foreshadowed, and a practical trial will consequently be awaited with interest by all those having experience of the unforeseen difficulties that often result from the behaviour of untried mechanical combinations

In order to reduce surface velocity of a distributing liner valve to a practical limit a motor has been designed by the author, as illustrated in diagrammatic section, fig 163, in which a revolving liner is caused to rotate once for four revolutions of the motor shaft, for which purpose the liner is provided with two port openings located opposite one another. On the liner being rotated these communicate alternately at each half turn of the liner with port openings, arranged on opposite sides of the motor cylinder for the induction of explosive mixture and exhaust of the products of combustion.

In this revolving liner-valve motor the admission and exhaust openings, *n* and *x*, are not placed quite opposite to one another, but at such an angle that one port, t^1, in the revolving liner, *r*, will commence to register with the induction opening, *n*, coincident with, or immediately after, the closing to the exhaust outlet, *x*, of the opposite port, t^2. The width of the ports is such as to cause one of each pair to register with one another for a period of about 200° of one revolution of the motor shaft so as to keep down internal resistance at high speeds to a negligible quantity.

In one of the plan figures the liner valve is shown in position, with the motor piston, *p*, at the end of the exhaust stroke, and in position for the commencement of the firing stroke in the other view—*i.e.*, separated by one-quarter of a turn of the liner, the liner rotating one-eighth of a turn for each stroke of the piston. The advantage of a revolving liner distribution is that at whatever varying speeds of the motor shaft, the timing of the opening and closing to both admission and exhaust remains constant, and in consequence is always maintained in exact step with the motor piston. Spring packing for gas

tightness is effected by recessing a key in the cylinder at each side of each port as shown at *e*; the liner itself has no rings, and is made as thin as practicable in order to minimise weight and keep down the surface temperature next the piston;

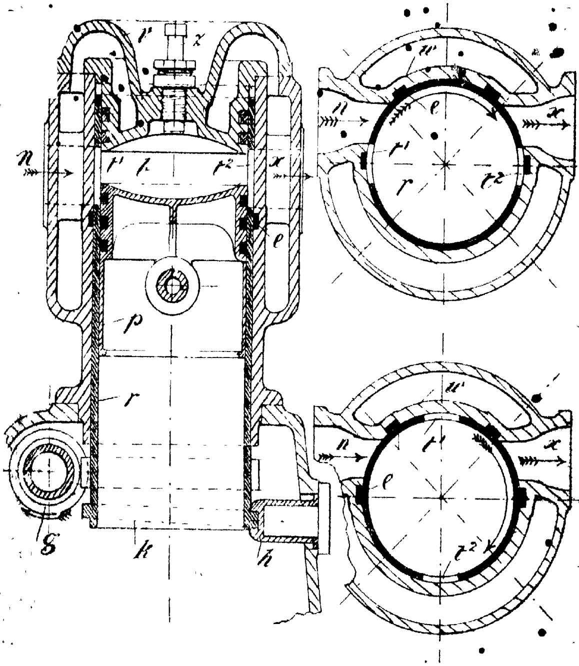


FIG. 163.—Cross-section of cylinder of petrol motor with slowly-revolving ported liner.

a flat, bow-shape spring is inserted behind each key. Lubrication is effected by a helical groove cut on the cylinder side of the liner, the groove having a series of holes perforated along its path, by which means oil from the piston is carried up and circulated along the full length of the liner, which is rotated by worm gearing at its lower end. A series of liners in a multiple-cylinder motor can be actuated by one lay shaft

running at the same speed as the motor shaft. In order to reduce surface friction and prevent grooving the liner is caused to move endways to a slight degree by the bearing shoe, *h*, and oblique flange, *k*.

Revolving Sleeve Valves.—In cylinder liner valve motors the elimination of cam- and spring-actuated poppets is obtained at the expense of a cylindrical valve extending from end to end of the motor cylinder, and is open to the objection of receiving the angular thrust of the working piston, besides having to be actuated from a gear drive enclosed within the crank chamber, thus entailing the dismantling of the entire motor in order to remove the valve. In the modified distribution illustrated by figs. 164 and 164A this objection does not exist, as the sleeve valve is limited in length to the combustion chamber. it is therefore independent of the motor piston, the drive, moreover, is located within an accessible and easily removable casing on the cylinder head. Referring to the two sectional elevations and half plan illustrating this cylinder-head revolving valve: the ported sleeve, *v*, is seen arranged between the water-jacketed extension of the cylinder, *c*, and a water-cooled cover enclosing the combustion chamber, *b*, formed with two portways, *t*, opposite two pairs of intake and exhaust openings, *n* and *x*, in the motor cylinder. The revolving sleeve, *v*, is provided with four equidistant ports, *r*, two of which at each quarter turn of the valve communicate simultaneously, first with the two exhaust outlets, *x*, and immediately following with the two intake openings, *n*; thus the sleeve revolves at a speed of one-eighth that of the motor shaft, or, in other words, at a peripheral or surface velocity of approximately 4 ft. per second in a motor having a 4-in. diam. cylinder and running at a speed of 2000 revs. per minute. The increased gas-way afforded by the double intake and exhaust is a very important feature, and renders quite feasible even higher piston speeds than are now considered practicable.

The sleeve is extended upwards to carry the gear ring, *g*, which meshes with the worm drive, *r*, both being enclosed oil- and gas-tight within the casing, *k*; through this, water in the space, *h*, circulates from the outer to the inner jackets by the ways, *w*, thus avoiding pipe connections. The inner cover is

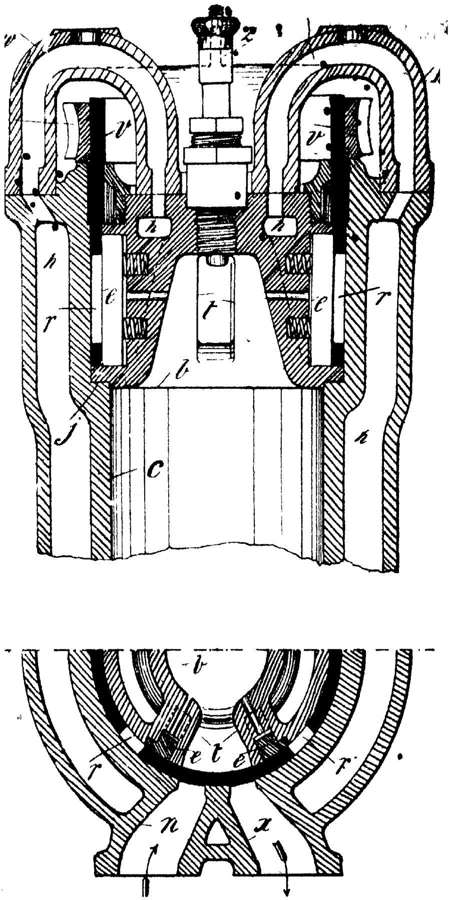


FIG. 164.—Part sectional elevation and plan of cylinder head of high-speed petrol motor with double intake and exhaust controlled by a slowly revolving sleeve valve—Butler.

securely held down to the ledge, *j*, forming thereon a gas-tight joint; the under edge of the valve also forms a gas-tight fit that effectually prevents leakage from the combustion chamber to the outside of the valve, and escape to the casing, *k*, is prevented by the metallic packing ring, *i*. The sleeve is made

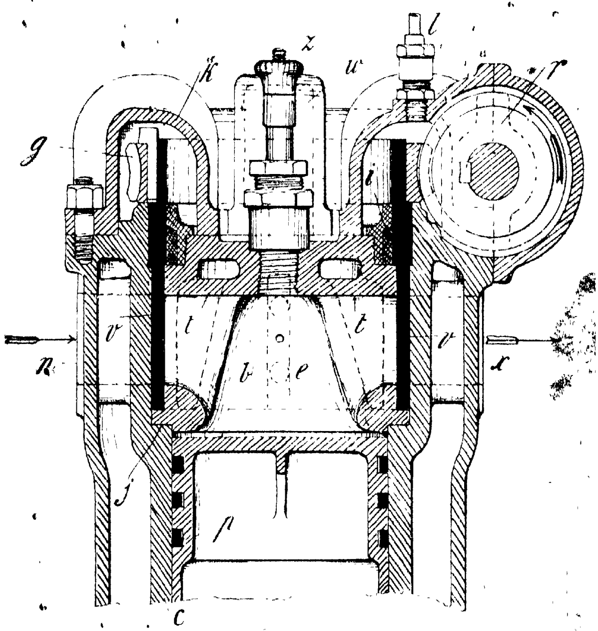


FIG. 164A.—Cross-section of cylinder head with double intake and exhaust controlled by a slowly revolving sleeve valve.

gas-tight around the inner periphery by keys, *e*, held up to the sleeve by springs and by gas pressure, and is effectually lubricated as well as the enclosed gearing by an oil-feed at *l*. The igniter, *z*, is in the centre of the combustion chamber, and the portways, *t*, which are of the shortest possible length, communicate with gas-way openings equal in area to nearly one-fifth that of the piston. the inlet and outlet velocity of the gases

does not therefore exceed 80 ft. per second with the motor running at a piston speed of 1000 ft. per minute.

Oscillating and Combined Revolving and Reciprocating Liner Valves.—Oscillating or part rotary and part reciprocating cylinder liner valves have been tried, as no very considerable success has been obtained with any of the several revolving liner valve motors that have been made, partly for the reasons stated and partly because of immature design, but mostly on account of either leakage past the packing rings, or wear and difficulty of holding these securely in position while passing the port openings; also scoring of the cylinder due to pressure on the keys, heat and insufficient lubrication *e.g.*, in the distribution used in the Argyle motor cars, the great advantage consists in the movement upwards of a cylinder liner during the compression and power strokes, thus carrying the liner port up past a circular packing ring, and in this manner effectually preventing loss of pressure through leakage to the inlet and outlet cylinder openings. However, to obtain this advantage with an oscillating movement the port in the liner must be of irregular shape, which in turn necessitates a deeply recessed cylinder head, thus adding to the difficulty of conveniently placing the igniter. To alleviate these and other faults associated with a simple rotary or oscillating movement the writer has designed a motor, fig. 165, in which a single liner having a combined rotary and reciprocating motion is used; thus a port, *t*, of normal shape and depth is moved up behind a packing ring, *r*, of considerable width during the whole of the pressure period of the cycle. The liner, *v*, is rotated by a skew wheel, *g*, gearing with another on the half-speed shaft, *h*. The bottom end of the liner is thicker than the part extending up past the heat zone, and is splined to allow of a free sliding fit within the driving ring. Reciprocating motion is derived from a rocker bar, *e*, linked to a strap, *p*, bolted around a groove on the bottom of the liner. the rocker bar is connected to the half-speed shaft by an eccentric drive, *c*. In the part sectional plan the port, *t*, is shown midway between exhaust and induction—*i.e.*, with crank at top centre; in this position the port shown in dotted lines, *t'*, is down to the level of the inlet and outlet port zone; but during the period of highest pressure

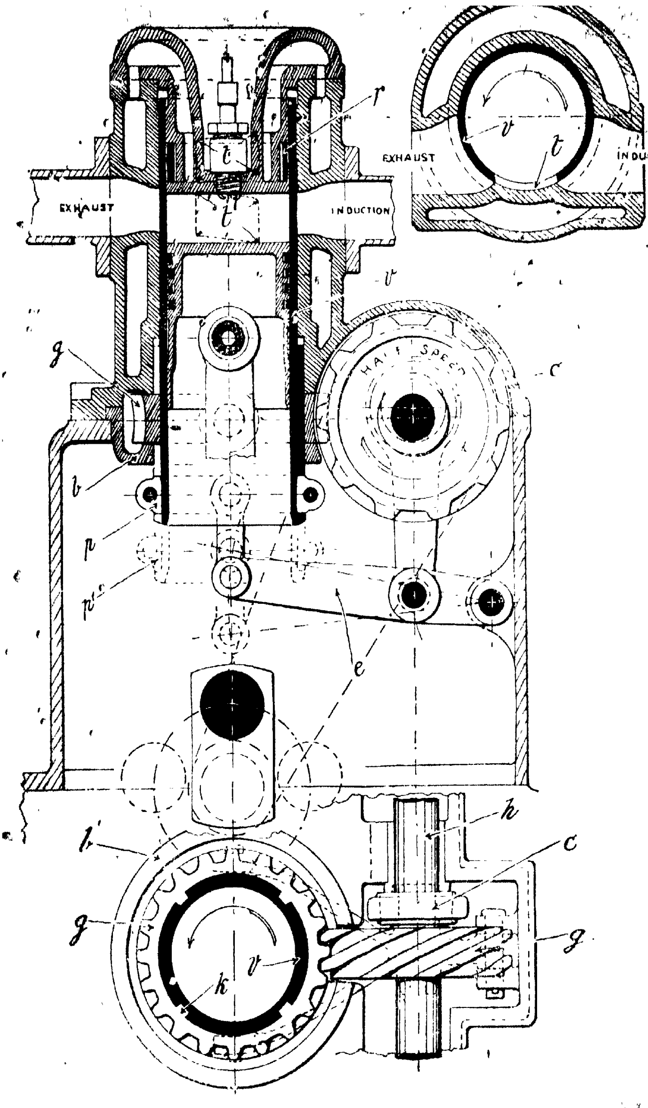


Fig. 165.—Cross-sectional elevation and plan views of four-cylinder petrol motor showing action of Butler's single-ported liner valve, with combined rotary and reciprocating motion.

—*i.e.*, with the crank again on top centre, the port is entirely covered by the broad packing ring, *r*, inserted in the fixed piston extension of the cylinder cover; thus its action is quite normal, as in ordinary piston valve practice, and leakage past the packing ring and round to either port is entirely prevented.

Reciprocating Cylinder, Piston, and Liner Valves.—As already explained, flat slide valves are not suitable for internal combustion engines these causes, although mitigated to some extent, also apply to piston valves, and, as it is impossible to distribute both admission and exhaust by one valve unless operated by a large cam gear, piston valves have not made much headway, and in practice in order to obtain a smooth working drive, either from cranks or eccentrics, two valves are found necessary.[1] One of the most practical designs is shown in fig. 166. In this connection it must be understood that no design in which the packing rings are exposed to cylinder pressure can be a success. Referring to the example illustrated, which represents an ordinary high-speed four-stroke engine, there are two auxiliary pistons, N T each connected through an eccentric to a half-speed shaft. The power piston is shown at the end of its working stroke, and the auxiliary piston, T, to be uncovering a belt of ports leading to the exhaust outlet, X. At the end of the exhaust stroke the eccentric will have moved into the position L from K, and be about to close the exhaust, and during the admission, compression, and explosion strokes the exhaust piston eccentric will move round from L to K, and so be in the position for again releasing the exhaust. The admission piston, N, is now at L, and during the admission stroke will move from D to E. An engine constructed in this manner, although not so simple nor cheaply made as an ordinary cam-opened spring-closed poppet valve motor, has some features in its favour—viz., an absolutely definite timing of the valve movements with quiet action at any speed; to which may be said further that with this distribution a certain degree of additional expansion is obtained which can be taken advantage of in the construction of an engine with auxiliary pistons of a larger diameter, so constituting, as it were, a compound engine. On

[1] Examples of the several methods of applying this principle are graphically outlined in *Internal Combustion Engine Design and Practice.*

examining this design it will be noted that the auxiliary piston, T, moves outward from E to K, during the power stroke, and

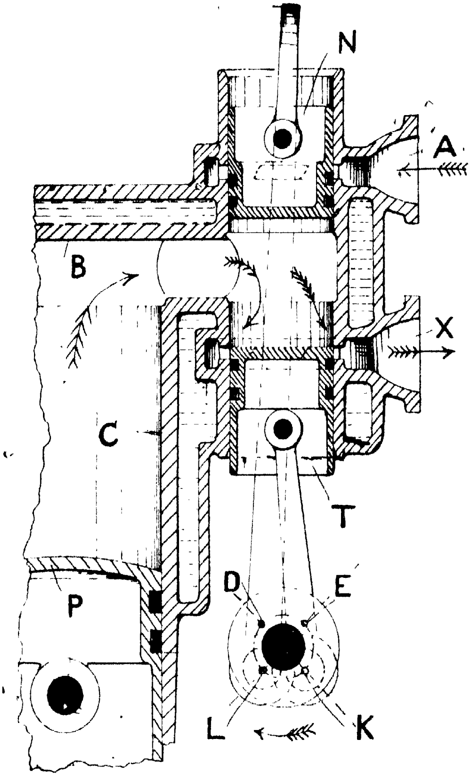


FIG. 166.—Cross-section of cylinder of four-stroke vertical engine with piston valves for admission and exhaust.

with an auxiliary piston of twice the area of the power piston an additional expansion to the charge can be obtained of about 50 per cent.

In the use of piston valves, once commonly used in two-stroke gas engines, for controlling the transference of the charge

from the charging pump to the power cylinder, and to time communication between the combustion chamber and ignition tube, the valves were actuated direct from the crank shaft, and served their purpose well. A single valve of this kind, however, cannot be used to control both the admission and exhaust in a four-stroke engine, as will be obvious upon an inspection of this problem, the time intervals between the periods of admission and exhaust being too close to allow sufficient movement of the valve. Also it is not feasible in practice to traverse a piston valve fitted with rings across portways open to the pressure of the explosions, the effect being to close in the rings, cause leakage, and sooner or later cause fracture.

In the Knight four-stroke automobile motor, illustrated by the diagrammatic section fig. 167, a similar effect to that above described is obtained by the use of a pair of ported liners arranged to slide between the motor cylinder and its piston, two liners being used, partly for the reason above stated and partly to obtain a sharper cut off than is possible with a single liner. Referring to the section illustrating this interesting distribution, which has been taken up with considerable enterprise and success by the Daimler Company, it will be seen that the power piston, P, is of ordinary construction, and drives on to a crank shaft, M. Between the piston and cylinder proper are two thin reciprocating liners, E V, forming an accurately ground sliding fit between one another and the cylinder and piston. A sliding motion of about one-fourth the cylinder diameter is communicated to each of these ported liners by rods working on to half-speed lay shafts, L, the respective position of the liners being indicated with the piston at the end of the exhaust stroke or commencement of the induction stroke. In explanation of this movement, it will be seen that the exhaust to T is cut off by reason of the upward movement of the slide, V, within the downward moving slide, E, the inlet port in V, on the other side, at this moment is seen to be on the point of opening to the port, N, for the supply of explosive mixture. The relative positions of the two liners with the two ports, N T, when the piston has completed its induction stroke—*i.e.*, after the crank has moved round some 10° or so past the bottom dead-centre, are as follows: Both liners now moving in the upward direction, but one faster

than the other, so that the port openings will be closed to the cylinder; during compression of the charge the liners still con-

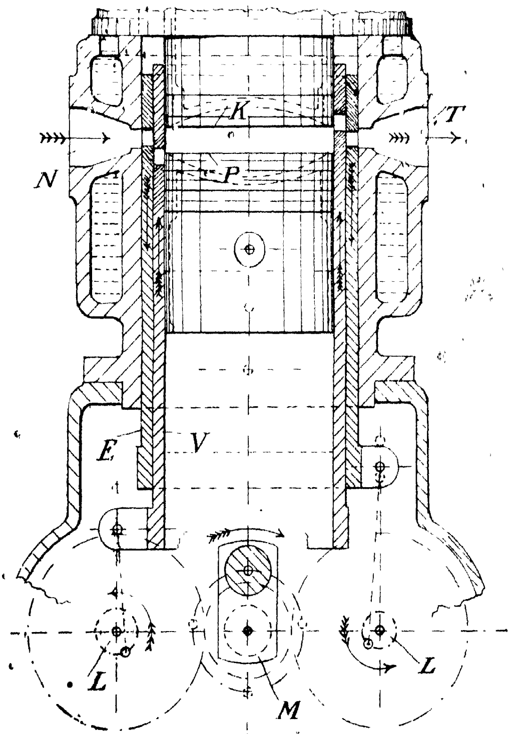


FIG. 167.—Diagrammatic section of Knight four stroke valveless motor with ported sliding cylinder liners.

tinue to move up, the ports in the inner liner getting behind a packing ring in the piston cover, K, for the commencement of the working stroke; the relative positions of the two liners when the crank has advanced to within 15° of the completion of the working stroke will be such that the two ports o[illegible] haust

will commence to register with one another and to the outlet at T, and remain open during the exhaust stroke.

The inner liner is about one-quarter of an inch in thickness and the outer about three-sixteenths, neither being provided with packing rings, gas-tightness around the inlet and outlet ports, for a portion of the stroke, being ensured by a most carefully ground and accurate fit one within the other. The working piston, P, is provided with rings in the ordinary way, as also the fixed piston, K, the removal of which renders access to the combustion chamber quite an easy matter. *N.B.*—An important function is served by the packing ring in the fixed piston, as during the greater part of the pressure period the liner ports are cut-off from the inlet and outlet ports, N T, so being both either covered or above the ring, K, and leakage from the combustion chamber to either the admission or exhaust opening effectually prevented.

The most notable advantages that may be derived from a motor in which all lift valves are eliminated are the absence of valve pockets and the possibility of higher speeds with more silent action. In regard to the area of port opening obtainable in this manner, it may be stated that the width of the port openings in a cylinder of 4-in. diameter, in order to provide an area of gas-way equal to one-seventh of the piston area, must be 0·4-in. with a length of port equalling one-third the circumference of the cylinder. A favourable feature of this, as with all liner or sleeve valve distributions, is the shortness and directness of the portways.

It is only natural that following the rather unexpected success of the Knight cylinder liner distribution, there should be a number of attempts to obtain a similar result with a single liner; but in practice the same difficulty presents itself as in the application of piston valves, viz., the impossibility of obtaining this with a regular crank-driven movement: either the liner must have a motion compounded of a rotary and reciprocating movement, as shown in fig. 165; or an oscillatory movement, as used in the Argyle motors, or again, have a motion derived partly from a crank or eccentric on a half-speed shaft, and partly through a system of links connecting the drive to the power piston connecting-rod or to the piston direct. Then

gain, even when so operated it is found that the resultant motion is not a regular one, and is influenced to a material degree by error of alignment, and especially by lost motion in the connecting pivots; the whole problem of single-liner admission and exhaust control is a particularly interesting one, in demonstration of which a complete chapter has been devoted to this subject in *Internal Combustion Engine Design and Practice*, the problem presenting so many factors for consideration.

Reciprocating Sleeve Valves.—There is, however, another way of tackling this problem of how to improve on the ordinary clack-valve distribution, and this is to either use a cam-operated sleeve in the head of the cylinder, or two segments, each separately operated. In solving the problem according to this method, the shorter and lighter the sleeve the better, as it is unavoidably dependent on spring action for the return movement, and must keep step at high speeds. One of the most practical distribution methods on this principle is that known as the Howard sleeve or cuff valve, illustrated in figs. 168 and 168A. In this the valve, *v*, free to expand like a packing ring, is contained within the cylinder head, *c*, in which are cast two pairs of ports, *x x′* and *s s′*, along two zones. The valve during the compression and power strokes covers these ports absolutely gas-tight, as it is quite free to expand, and is then held tight up to its circular seat by gas pressure, but the valve is motionless during this period, which is an important consideration. Towards the end of the power stroke the cam, *k*, rocks the double lever, *l*, thereby depressing the crosshead, *h*, and the valve through rods, *d d′*, until the two ports, *x x′* (which extend as shown in the plan section for quite three-fourths of the circumference of the cylinder), are fully opened. Near the end of the piston's up stroke the valve is then moved up until, first closing the exhaust it opens the lower pair of admission ports, *s s′*. The spring, which is in length about six times the necessary motion, has a depression of about 50 lbs., which is sufficient to keep the roller well down to the double cam at the highest speeds and without the slightest clatter even at over 2000 revs. per minute. The width of the ports in a 4-in. diam. engine is 0·28 in., the total movement of the sleeve is therefore twice this, plus overlap—*i.e.*, 0·65 in.; but

as the weight of sleeve and operating gear has been reduced to a fine limit, its working is surprisingly smooth. *N.B.*—The

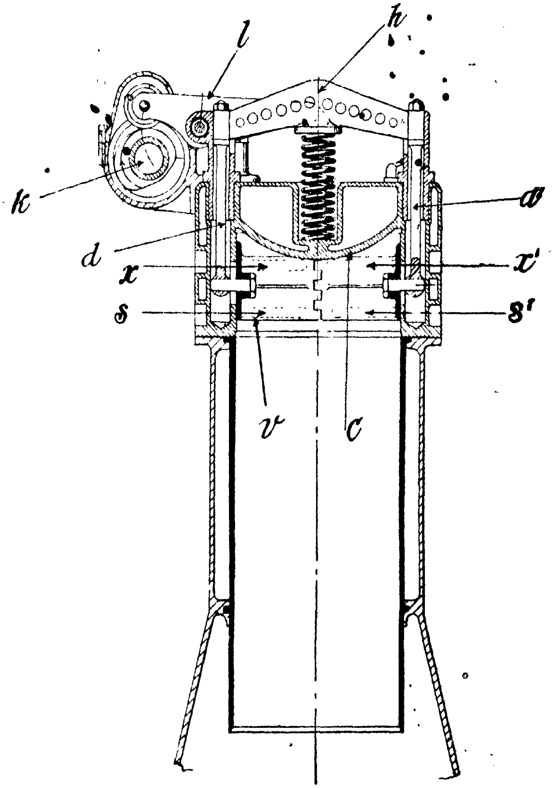


FIG. 168.—Cross-sectional elevation of 4-in. petrol motor, showing arrangement of cylinder head for the Howard sleeve valve.

pening thus afforded is practically one-fifth the area of th motor piston and equal to a poppet 2·25-in. diam. × 0·3-in. lift. A cylinder-head reciprocating sleeve valve can be in halv

just as a cylinder single liner valve can, and each operated separately, thus reducing the necessary motion but not halving

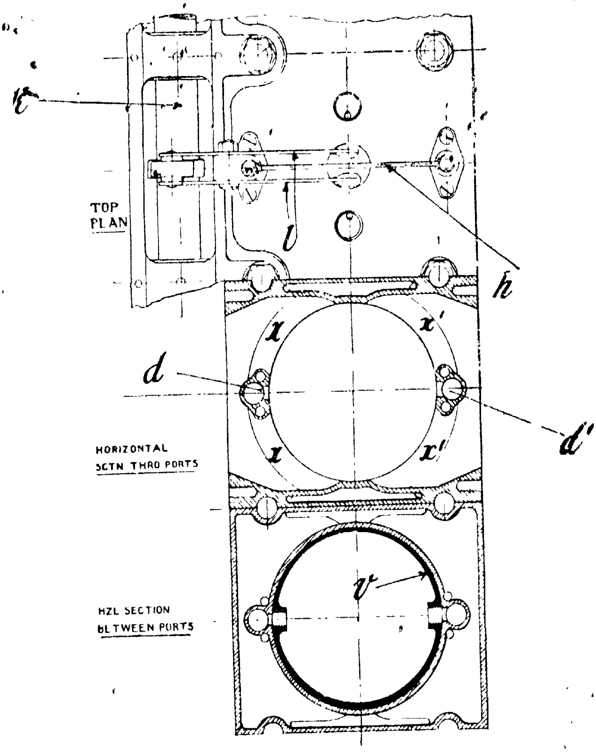


FIG. 168A.—Plan views of four-cylinder motor fitted with the Howard sleeve valve.

it, as the ports in place of having a length equal to three fourths or more of the cylinder circumference must be limited to less than one-half. the ports must therefore be one-third wider. However, any reduction in the motion of a valve dependent on spring action must be accredited as a factor to th

good. Following on these lines, the Cooper cylinder-head split-sleeve valve has been designed. This, illustrated in fig. 169, consists of a split flanged sleeve, *s s'*, fitting between the piston projection, *h*, of the cylinder head and an enlarged extension

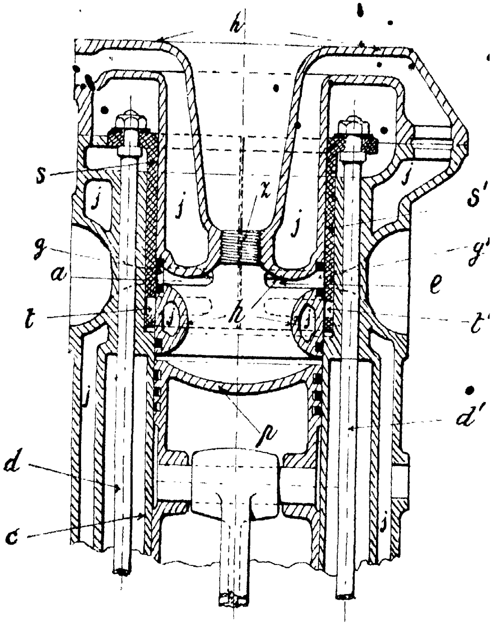


FIG. 169.—Sectional elevation of S. Cooper's cylinder-head split-sleeve valve.

upwards of the cylinder, *c*. Each sleeve segment is separately operated through rods, *d d'*, from a half-speed cam shaft below. The action is quite simple: for instance, with the piston on top, as shown with charge compressed, the valve is in its lowest position with ports, *t t'*, behind the jacketed extension of the fixed piston, *h*. During the exhaust stroke the segment *s'* will be raised until the port *t'* places port *g'* into communication with

the outlet e, and is then quickly lowered again to the position shown. Immediately following this, the other segment s will be raised for t to be open to g and a, and then be as quickly shut. Narrow packing rings are sprung into grooves on the fixed piston, concerning which the two above and below the

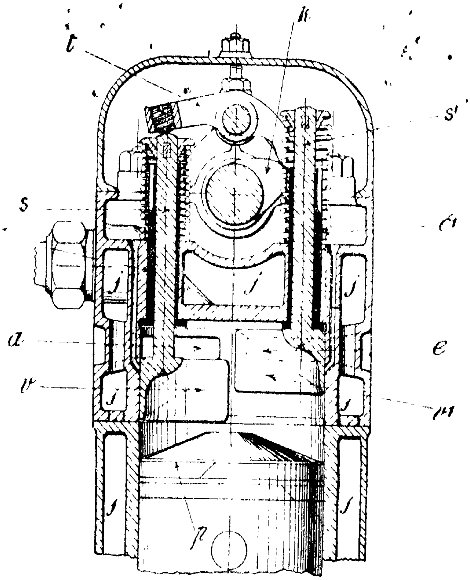


FIG. 170.—Cross-sectional elevation of cylinder, showing the Stanley slide valve arranged with overhead operating gear

ports, $g\,g'$, are not sufficiently shielded, and certainly do not appear capable of maintaining a gas-tight fit between the inside and outside ports, but this is a detail that can be rectified; the actuating rods are held in sufficient tension by springs to keep the rollers at the bottom end in continuous contact with the operating cams when running at high speeds.

The most thoroughly well-thought-out design of cylinder-head slide valve is undoubtedly the Stanley, shown in fig. 170.

RECIPROCATING SLEEVE VALVES.

In this distribution every part is self-contained with the cylinder head and enclosed, there are no packing rings required, and the moving parts are as light as can be. The construction is obvious and explanation unnecessary, further than to mention that the segments, $e\,e'$, are purposely shown in full open and closed positions for clearness, the stems, $s\,s'$, are carried by eccentric bushes, $c\,c'$, to enable any slight error in alignment to be corrected and to compensate for wear

The segments do not require any packing, as during the whole pressure period they are held gas-tight up to a ground-in fitted shoulder. There are no portways through the segments, and for this reason these have been reduced to a length just sufficient to wear well, and, needless to add, their weight, including stems and rockers, is not materially greater than a pair of poppets; while the segments have the great advantage of opening a free and unobstructed gas-way, and furthermore, of opposing no gas-pressure resistance to the operating gears, which is the cause of most of the wear on the cams of all unbalanced exhaust-lift valves.

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